THE ANIMAL'S WORLD

ORIS L. MACKINNON

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THE ANIMAL'S WORLD

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THE ANIMAL'S WORLD

BY

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PREFACE

THIS book is my attempt to find some other way than the text-book way and the nature-study way of interesting a child in the science of living things. Admittedly I set myself a very difficult task; and no one is better aware than I am of the shortcomings of the method I have adopted. What encouraged me to proceed was what happened during a course of broadcast talks in which I had my share.[1] This course apparently reached a wide audience, if I may judge by the letters I received from people who wanted to know where they might get some book written on the lines that I had followed at the microphone.

So, in modified form, these broadcast talks have been used as the basis of some thirty chapters in what follows. I have added the remaining chapters to make the necessary connection between one topic and another.

The principles of biology apply equally to animals and plants; but this book has an obvious bias to the animal side. For, since I am a zoologist, I feel better qualified to deal with the life of animals; and, moreover, I believe that most people find it much easier to approach biology from that aspect. The plant, however familiar and however much admired, is always more elusive and more remote than the animal when we consider it as a living being. So I have called my book *The Animal's World*, and have introduced chapters on plant biology only where it was obvious that the plant and animal worlds are so interdependent as to be inseparable.

Since, from the point of view of the biologist, Man is one with the rest of the animal kingdom, I have used him freely in illustration of certain principles. This has the advantage that even if the reader does not set up an aquarium or breed silkworms, he has at least his own body to observe. And it also serves the purpose of bringing to his notice a fact too often forgotten; which is that, for the great majority of animals, Man is merely 'incidental' – an inhabitant of their world, it is true, but at least as much an interloper as he is a brother.

I am much indebted to the B.B.C. for their kind permission to make use of the material I employed in broadcasting; and to my father and to two of my colleagues, Miss A. Shore and Dr. N. Penston, for very helpful criticism. I would also express my thanks to all the authors and publishers, artists and photographers whose names are given under individual pictures, for permission to reproduce copyright illustrations. (I have taken the liberty of simplifying legends and lettering in many instances.) Lastly I would thank my friends the publishers for their encouragement and their enthusiastic co-operation.

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[1] *How Life is Lived.* A Course of Elementary Biology arranged by the Central Council for School Broadcasting, 1933–35.

Chelsea,
1936

D. L. M.

CONTENTS

CHAPTER I · BEING ALIVE

PAGE

Living and Not-living – Movement – The Cat and the Kettle – Fuel for the Cat – Sensitiveness – Self-mending – Growth – Cat and Kittens 1

CHAPTER II · WHAT IS AN 'ANIMAL'?

Plants are alive although they don't move about – The Plant makes its own Food before it feeds – The Animal is much more energetic and sensitive – Powers of Growth – Cuttings, Seeds and Eggs 5

CHAPTER III · THE ANIMAL'S BODY

Parts of a Kettle – Organs of a Body – Insides – Division of Labour – A single Control – The living Stuff – The same Animal but different 9

CHAPTER IV · SKELETON AND MUSCLE

The Jelly-fish – The Skeleton as a Support – Inside Skeletons and outside Skeletons – The Skeleton as Armour – The Skeleton as Attachment for Muscles – Muscle is Meat – What Muscle is for – How the Muscles of the Arm work – 'Involuntary' Muscle – Parts of the human Skeleton – All the large Animals have the same sort of Skeleton 13

CHAPTER V · GETTING OVER THE GROUND

Why Animals move about – Limbs of a Dog – The Horse has only one Toe – The cloven Hoof – Flat Feet and Toe-walking – Pretend to be a Newt – And then a Rabbit – Gait – The Frog and the Kangaroo – The Bird's Foot – And the Monkey's 20

CHAPTER VI · HOW ANIMALS MOVE IN WATER

Stream-lining – Tail and Fins – Sculling – The Fish's Gas-bag – The Whale is not a Fish – What makes the Whale look like a Fish – The Turtle's Trudgeon Stroke – A Use for Webbing 28

CHAPTER VII · HOW ANIMALS MOVE IN AIR PAGE

Why Flying is difficult – Animal Parachutists – Flying is well worth the Trouble – The Bird solves the Problem – Stream-lining again – Wings are Arms – Feathers – Rowing in the Air – The Bat's Plan – There once were flying Dragons – The Insect's Wing 36

CHAPTER VIII · A BIRD'S MUSCLES

Why the Bird's Arm is so skinny – Why the Bird's Breast is so plump – Major and Minor – The Merrythought – The Shoulder-pulley – Two-legged Toe-walking – Why the sleeping Bird does not fall off its Perch 44

CHAPTER IX · CREEPERS AND CRAWLERS

How the Fly can walk upside-down – Watch a living Earthworm crawl – Bristles give a Hold – You can swallow Food even when you stand on your Head – The Snail's Foot – A moving Staircase – A Snake is not a Worm – Snakes once had Legs 50

CHAPTER X · THE BREATH OF LIFE

Living Things are burning – Slow Combustion – Why Burning is necessary – Waste from the burning – No burning without Oxygen – Breathing – Lungs – A Suction-pump – Blood carries the Gases – The Blood circulates – Why the Heart beats 57

CHAPTER XI · HOW ANIMALS BREATHE (i)

Plants breathe through Leaf-holes – Breathing-apparatus of Rabbit and Bird compared – Why Birds need so much Oxygen – The Frog's Force-pump – Skin-breathing – Gills 63

CHAPTER XII · HOW ANIMALS BREATHE (ii)

The perfect Skin-breather – The Snail's Lung is on its Back – Pond-Snails – The Insect's Air-tubes – Compare Insects with Birds – The Water-Beetle and the Caddis 70

CHAPTER XIII · FOOD, AND WHY ANIMALS EAT IT

What is 'Starvation'? – Stores of Fuel in the Body – Food and Food-stuffs – The three great Food-stuffs – What they are used for – Diet – Necessary Extras – Water is all-important 77

CHAPTER XIV · THE FATE OF A MEAL

PAGE

The Food Canal – The Names of its chief Parts – How the Food is moved along – The Food is gradually changed – Why you feel sleepy after a big Dinner – The Blood carries Food as well as Oxygen – The Liver as a Filter – The Rabbit's Appendix 84

CHAPTER XV · THE GREEN PLANT

Plants must feed – The Mouse and the Daisy – Sunshine is necessary if the Plant is to make Food to feed on – The Plant can use the Animal's waste Gas – What the Roots do – Sugar and Starch – A Starch-print – The Plant gets more from the Soil than just Water – If there were no Plants, there would soon be no Animals 91

CHAPTER XVI · FOOD STORES IN PLANTS

A Store-cupboard for the Winter – And for starting Growth in Spring – The Potato is not a Root – But the Carrot is – The Potato's Eyes explained – The Onion and the Hyacinth Bulb – The Bean and its Food-stores – The Seedling 97

CHAPTER XVII · HOW ANIMALS KEEP WARM

Comfortable Warmth – How to keep warm on a Desert Island – Taking a Frog's Temperature – The Importance of Surface – Warm-blooded Animals – The Bird's 'Normal' – Sweating and Flushing – An Appetite for Fat – Animals' Clothes – Why a hot Dog lolls out his Tongue – Why Birds sit on their Eggs and on their Nestlings 105

CHAPTER XVIII · WINTER SLEEP

What is Sleep? – Plants are obliged to rest at Night – The Plant economises its Water-supply – Winter in the Plant World – Why a Plant loses its Leaves – Evergreens – Drawing on Food-stores – Spring's Awakening – Winter is hard on Animals – Migration – Living on one's own Fat – The Advantages of being Warm-blooded 114

CHAPTER XIX · HOW ANIMALS FEED (i)

Herbivores and Carnivores – Why the Rabbit and the Sheep have to eat so much more than the Cat and the Dog – Why a Lion's Body looks so much leaner than a Zebra's – What you can guess from looking at an Animal's Teeth – A Bird chews its Food in its Stomach – Chewing the Cud 123

CHAPTER XX · HOW ANIMALS FEED (ii)

PAGE

Why Earthworms come to the Surface – How the Worm pulls Leaves into its Burrow – Digestion outside the Mouth – The Worm eats its Way through the Soil – The Gizzard again – Worm-castings – The Earthworm as Agriculturist – Screen our Food from Flies – The Butterfly's Tongue 130

CHAPTER XXI · NEWS OF THE WORLD

The World we know is a World of the Senses – The Position of the Sense-organs – The Animal's Sense-World is different from our own – The Nervous System – You cannot see without a Brain – Inside Information – The Use of a Stomach-ache 137

CHAPTER XXII · THE SENSE OF TOUCH

The Skin as a Sense-organ – Touch, in inverted Commas – Where the Touch-corpuscles lie – Testing for Touch – The Part played by Hairs – The Cat's Whiskers – Feelers 141

CHAPTER XXIII · HOW ANIMALS TALK TO ONE ANOTHER

Adam's Apple – Sounds and Words – Animals' Sound-making is like a Baby's – The Dog understands Words that interest him – Parrot Language – Where the Bird's Voice comes from – The Frog's Amplifier – The Grasshopper speaks with its Legs – The Conversation of Ants – The Bee's Dance 145

CHAPTER XXIV · ANIMALS' EARS

The Ear is a 'Balance'-organ as well as an Organ of Hearing – The Ear of a Jelly-fish – Grasshoppers on the Telephone – Whistling to a Caterpillar – The Spider and the Tuning-fork – The Human Ear – The Dog hears better than we do – Ear-trumpets – The Ear in the Bird and the Frog – What the Slow-worm heard – Ear-stones 153

CHAPTER XXV · THE SENSES OF SMELL AND TASTE

The Smell-world of a Dog – Recognition by Smell – Danger-signal and Track-sign – Smelling under Water – Test the Bee's Sense of Smell – Antennæ as Smell-organs – The Oak-Eggar Moth – Taste is largely Smell – Tasting with the Skin 163

CHAPTER XXVI · THE ORGAN OF SIGHT PAGE

The Eye-ball – The Eye likened to a photographic Camera – Focusing – Accommodation – Stereoscopic Vision – Its Advantages – Colour – Perhaps there are more Colours than those in the Rainbow – Colour-blindness 170

CHAPTER XXVII · HOW ANIMALS LOOK AT THE WORLD (i)

Seeing differently – Cats' Eyes – A third Eyelid – The Size of Eyes – Their Position on the Head – A Bird's-eye View – Seeing under Water – Colour-sense in Dogs 176

CHAPTER XXVIII · HOW ANIMALS LOOK AT THE WORLD (ii)

'Seeing' Light and getting Pictures – The Snail's Horns again – The Earthworm has no Eyes but is sensitive to Light – The short-sighted Caterpillar – The Butterfly is good at seeing, but cannot focus – To show that a Bee can tell one Colour from another – The Insect's Eye is a Lattice Window 183

CHAPTER XXIX · BRAIN AND NERVES

Response to Stimulus – The Nervous System considered as a Telephone Service – The Central Exchange – Co-ordination and Control – The chief Parts of the Brain – Mapping out the Cerebrum – How the Surface is increased – Where Man is Inferior to other Animals – And where he is their Superior 189

CHAPTER XXX · ANIMAL BEHAVIOUR

Six Brains compared – The same Parts but the Proportions different – The Nervous System of an Earthworm – Study Behaviour – Practice makes perfect – Knowing without learning – Intelligent and instinctive Behaviour – The Monkey dealing with a new Problem – Compare a Dog's Behaviour with a Hen's 197

CHAPTER XXXI · HOW ANIMALS HIDE

Escape – The Battle is not always to the Strong – Matching the Background – The Value of keeping still – Pretending to be dead – Camouflage – Some Insect Disguises – Stick and Leaf Insects 205

CHAPTER XXXII · EGGS PAGE

All Animals come from Eggs – The Inside of a Hen's Egg and what the Parts are for – The Life-spot – Frog's Spawn – The Size of the Food-store in different kinds of Eggs – Insects' Eggs 212

CHAPTER XXXIII · THE CHILDHOOD OF ANIMALS (i)

The Bird's Nursery – The Number of Eggs in Relation to Position and Shape of Nest – Incubation – Dependent and Independent Young – The Food Question – Fruit-eating Birds may help the Gardener – Learning to Fly – Cat and Kittens – Mice, Kittens and Lambs compared – The Mother's Milk – The Value of Play 220

CHAPTER XXXIV · THE CHILDHOOD OF ANIMALS (ii)

Animals that 'metamorphose' – The Silkworm is an Insect – Hints on rearing Silkworms – The Larva – Growth – The Cocoon – What Silk really is – The Pupa – The great Change – The Dragonfly – The Ants' Nursery – An 'Ant's Egg' is a Cocoon – Tadpole into Frog 228

CHAPTER XXXV · HOW ANIMALS LIVE TOGETHER (i)

Sociability – The Family and the Tribe – Butterflies and Frogs have no Family Life – It is very different with Birds and with Mammals – But their Family Life soon ends – The Rookery – The Wolf-Pack – The Herd – Different Duties for the Members 237

CHAPTER XXXVI · HOW ANIMALS LIVE TOGETHER (ii)

Life in a Community – The Hive – The Comb – Honey-getting – Bees' Bread – Wax-making – The Nursery – Three Types of Bee – The Bees make their own Queen – Jack-of-all-Trades – But Master of each in turn – Living Radiators – And Ventilators 245

CHAPTER XXXVII · THE FLOWER AND THE FRUIT

The Flower is not mere Decoration – The Parts of a Flower – Pollination – Fertilisation – The Seed and the Fruit – Juicy Fruits – Colour as Advertisement – Bringing the Seeds to Earth – The Value of Distribution – Prickly Fruits and their Dispersal – The Dandelion-Clock 252

CHAPTER XXXVIII · INSECTS AND FLOWERS PAGE

Petals and Scents – The Fly and the Buttercup – Pollination by Insects – Where the Bee sucks – The Honey-Bee's Brush and Basket – Bumbles and Red Clover – Why Honeysuckle smells sweeter in the Evening 258

CHAPTER XXXIX · PARTNERS 265

INDEX 267

CHAPTER I

BEING ALIVE

LIVING AND NOT-LIVING – MOVEMENT – THE CAT AND THE KETTLE – FUEL FOR THE CAT – SENSITIVENESS – SELF-MENDING – GROWTH – CATS AND KITTENS

BEFORE we go on to consider the lives of animals, it would be a good plan to get clear as to what we mean by 'life.' It is a word we use all the time, and in a vague way we know what we mean by it: but I assure you it is not really so easy to explain why we say that some things are 'living' and that others are not.

You and I are alive: so is the cat by the fire, and the fly on the ceiling, and the geranium on the window sill. The cushion the cat is sleeping on is not alive, the tables and chairs are not alive, the ceiling is not alive, nor is the kettle in which the water is boiling for our tea. That is all very obvious, perhaps. But can you explain to me why it is fair to say that the cat, for instance, is alive, but that the cushion and the kettle are not? Can you put into words what is the difference between them?

The first thing you will probably say is that the cat can move but the cushion and the kettle can't move. Even in its sleep, the cat twitches its whiskers, and, if a fly settles on its ear, it twitches the ear to shake the fly off: and presently the cat will wake up, yawn, stretch its legs and move about. That, you would say, distinguishes the living cat from the not-living things in the room – the power of movement.

I would agree at once that this distinguishes the cat from the cushion. But please notice that there *is* some movement going on where the kettle is concerned. Now that the water is coming to the boil, the kettle is rattling its lid.

And, if movement is the thing that distinguishes the living from the not-living, what about the geranium? We agree that the geranium is alive: yet the geranium seems stiller than the kettle. So perhaps the power of movement is not the real distinction?

But supposing you put it rather differently: supposing you said that you consider the cat to be alive because it can move of itself. Then I would agree that you have hit on an important distinction between it and the kettle. The kettle's lid is being moved by the steam beneath it. The kettle cannot lift its lid up with its spout. The kettle's lid is being moved *for* it: whereas the cat is twitching its whiskers or moving about the room *of its own accord.*

The kettle's lid is being moved by the steam from the water boiling inside it. What makes the water boil ? The fire, of course. The fire that is destroying the coal heats the water until it boils and gives off steam. But if fresh air cannot get to the fire, the flames die down and the fire goes out. And when the coal is all burnt, again the fire goes out. When either of these things happens, the kettle ceases to boil, and of course its lid ceases to be moved up and down.

The cat would also cease to be able to move if it got no fresh air and if it got no more fuel. The cat can move only so long as it has something inside it that can be burnt; and it cannot burn that something unless the important gas in fresh air, the gas called oxygen, comes as freely into its body as the draught from the room blows into the grate and up the chimney. When I talk of fuel for the cat's body I don't mean coal, of course. But there are other sorts of fuel besides coal; and the cat's fuel is *food*, or what has been made from food. When these fuel stores in the cat's body are used up, the cat must be stoked: it must have something more to eat. Living things must have food if they are to go on being alive, and they must also breathe if they are to go on being alive.

Our cat and our boiling kettle on its fire both need fuel and they both need oxygen if they are to keep up their power of movement. But now here comes the difference again. The kettle can do nothing about providing a new store of force for lid-lifting. If someone doesn't put more coal on the fire for it, the movement of the kettle-lid comes to an end: and that's that. But the cat, the living being, can put matters right for itself. Look now ! the cat has got up and gone across to its saucer and is eating liver and lapping up milk. If we had left no food there for it, the cat would have gone to catch a mouse or a bird to eat. And if the room went on fire the cat would try to get out into the fresh air and so avoid suffocation.

This very real difference between what is living and what is not living is a difference made up of two parts. Take the case of the fuel-getting. First, the cat *feels* hungry: that is the sign its body gives it that the fuel is running out. Second, the cat then proceeds, of its own accord, to satisfy that need. The cat can feel what is happening, and it can do something to help its body out of the difficulty.

To be sensitive to a stimulus and to give an effective response to that stimulus – these are characteristics peculiar to living creatures. The dictionary says that a stimulus is 'something that rouses or excites.' Now in the case we were considering, the stimulus was the feeling of hunger; the feeling of hunger excited or roused the cat to action. Then, 'effective response.' That action by the cat, the going in search of something to eat, was the cat's response, or answer, to the stimulus. And it was an effective response because it served a useful purpose: it put matters right when they were going wrong, and the cat could go on moving and being alive.

We are apt to think of only one kind of sensitiveness – sensitiveness to pain. And in the first example I gave – the cat's hunger – the stimulus probably was a slight warning pain in the stomach. But the living creature is sensitive to ever so many sorts of stimulus besides pain. If the cat were not sensitive to touch, it wouldn't have flicked its ear when the fly settled there. If it were not sensitive to light, it couldn't have seen the saucer where the food was. If it were not sensitive to the smell and taste of things, the cat would eat lettuce or bread-and-jam as eagerly as it is now eating liver and milk.

Everything wears out in course of time. The soles of your shoes wear thinner and thinner until holes come: the bottom of the kettle wears thinner and thinner in the heat of the fire until holes come: the cat's fur wears out and the hairs fall off. But your shoes cannot grow new leather; they have to be sent to the shop to be mended: and the kettle must be patched with metal at the ironmonger's. What is not living cannot mend and repair itself. But the cat makes new hairs to replace the ones that have fallen out; and as fast as the pads on its paws wear out, new, firm skin is grown to replace the old skin. This power of repairing itself is peculiar to what is alive.

The repairing of the living body is done with some of the food. A good deal of the food is used for fuel: but the rest is used for the repairs. Now this is very extraordinary when you think of what the food is. The cat eats liver and drinks milk: liver and milk seem very different from hair and skin, but the cat can use liver and milk to make new hair or new skin, or new anything that is required. The shoemaker uses leather to patch your leather shoes: the ironmonger mends the iron kettle with more metal.

But the living body – your body, just like the cat's – does its mending with stuff that is apparently very different from the stuff that had got worn away or lost.

When the cat is young, it grows. It begins as a kitten; and it gradually increases in size until we say that it is a full-grown cat. You begin as a baby, you become a child, you go on growing until you are a man or a woman. The geranium plant is much larger than it was when you bought it a month ago. But the kettle was always the size it is now, and it will never be any larger. Here, then, is another very important difference between what is alive and what is not alive. It is really connected with the last difference. For the growing is also done with food the living creature takes in. When there is more food than is needed for the fire of life and for repairing worn-out parts, the body builds with it additional muscle and additional bone and additional skin, or additional stem and leaf stuff – the result being that, for a time, the creature gets larger and larger.

Now lastly – living things differ from not-living things in being able to give birth to young. After it has finished flowering, a plant will have seeds; and if these seeds are planted in the ground, a new crop of the same kind of plant will sprout up. Human mothers have babies. Every now and then the cat has kittens. One takes that sort of thing for granted. But you would be very much astonished if you came down one morning and found six baby kettles sitting round the big kettle on the hearth! If there were no men left alive to make kettles, there would soon be no more kettles in the world. But even if there were no human beings, there would still always be plenty of cats.

CHAPTER II

WHAT IS AN 'ANIMAL'?

PLANTS ARE ALIVE ALTHOUGH THEY DON'T MOVE ABOUT – THE PLANT MAKES ITS OWN FOOD BEFORE IT FEEDS – THE ANIMAL IS MUCH MORE ENERGETIC AND SENSITIVE – POWERS OF GROWTH – CUTTINGS, SEEDS AND EGGS

IN last chapter I counted the geranium plant among the living things in the room. I admit that it is very much more difficult to show that the plant is alive than to show that the animal is alive. But if you know enough about plants to apply the tests for 'livingness' that I have been giving you, you will find that these really fit.

Plants are sensitive to certain stimuli and they make effective responses to these. Plants get their own food and their own oxygen. They repair their worn-out parts. They grow – and usually much faster than animals. They have young.

And what about movement? Well, of course it is true that oak trees and cabbages and geraniums don't move about: they stay rooted to one place the whole of their lives. Nevertheless, there is some movement shown by plants – real self-movement, I mean. When you say, 'The branches of that tree are moving,' you mean that they are *being* moved, by the wind or by the boy who has climbed up the tree to gather apples; which is quite a different thing from a spontaneous movement coming, as it were, from inside the living being. But some of the real self-movements in plants you know very well. The daisy, for instance, folds its petals together at night; the sunflower moves its head from one side to the other as the sun goes across the sky. If you flick the leaves of the wood-sorrel plant, the three little leaflets will fold down against the stalk. And if you take a match and stroke with it the under side of a young, straight tendril of the bryony plant, the tendril will bend while you are looking at it.

But I agree that plant movements are slow and don't show easily, as a rule. You would be quite justified in protesting that movement is not such a characteristic power of living plants as it is of living animals. All I am saying is that plants *are* capable of doing some movement of their parts; and that, along with the other things, like needing food and repairing their worn-out parts, goes to show that they are alive.

Now if the animal and the plant are both living beings, how can I tell which is which? That seems a silly question to you. The cat is an animal, the geranium is a plant; you have no doubt about that. I daresay. But can you give me your reasons for saying that the cat is not a plant and that the geranium is not an animal? For the moment leave movement out of it, and give me another difference, a really important one. It is not so easy. . . .

If I were asked that question, the answer I would give is that I know the cat is an animal because it can't make its own food. That really is the great, fundamental difference between an animal like a cat (or a human being, for that matter) and a plant like a geranium or an oak tree. The green plant can make its own food. The animal can't.

The cat eats all sorts of things – the liver and fish and milk we provide, or the mice and birds it catches if it is in a wild state. But that food is already 'made' stuff. The cat can't join water and gas and salts together to make the liver and milk, before it begins to feed on them: but we find that the green plant can make foods, just as complex as these, from the air and from what comes in by its roots with the water from the soil. (For more about this, see Chapter XV.)

Once we agree about this important difference between the cat and the geranium, all the other differences between the two sorts of living beings come naturally.

The power of movement, for example. The plant doesn't have to move about because it can feed best by staying in one place: the things for making its food come to it, in the air and in the water from the soil. Whereas the animal has to move about in order to find its ready-made food.

Then, sensitiveness. Plants are sensitive to a few stimuli, such as light and moisture. But animals are ever so much more sensitive than plants are to things in general. The geranium cannot see, nor can it hear, smell or taste. The cat can do all these things. And after what I have been saying about the food, I am sure you begin to realise why. In order to find where its food is, the cat must be guided in the right direction. That is what its eyes and nose and ears and whiskers do for it. They guide the cat as it moves about in the room or in the forest seeking its food. And these sense-organs, as we call them, also guide the cat to where its friends are, and help it to escape from its enemies. Since the plant does not have to move about, sense-organs are not needed.

Next, the power of growth. Plants grow at a tremendous pace; most of them grow far faster than animals. Part of this is again connected with their staying still in one place. In last chapter I explained that food is needed for two main reasons – partly for fuel which can be burnt in the living body to give energy to do things, and partly for making new body material. Now the animal is so energetic that it uses up a tremendous amount of its food for doing things with. Every time the cat twitches its ear, food is required to supply power even for that; and when the cat runs about actively, a great amount of fuel gets burnt. And being so energetic also means that there is more wear and tear to the body; again, food is needed to keep the cat's body in condition. Indeed so much food gets used in these ways – in moving and in patching up – that there isn't a big enough supply to make the body grow at a great rate. But the plant spends far, far less than the animal on movement; and its parts don't wear out so fast, because they are not called on to do such strenuous work. So there is more left over of the food to put into the business of growing.

Lastly, there is the power of having young ones. Probably your geranium was not grown from seed, but from what the gardener calls a slip or a cutting – a shoot cut off from another geranium and planted in the ground, where it grows out roots. And with some kinds of animals you could do this too. You couldn't do it with a cat, of course, or with a frog, or with any of the large active animals. But you could do it with a sponge. Perhaps you don't believe me when I say that your bath-sponge was once an animal living in the sea. Even if you saw a living bath-sponge with your own eyes, still you mightn't believe it was an animal, because it sticks to a rock and cannot move about. And the sponge has no sense-organs; it is as blind and deaf as a plant. Still, I know it is an animal, and not a plant, because it feeds on ready-made stuff that it catches; it can't make its own food-stuffs as a seaweed can do. These rather plant-like animals, such as sponges, may be treated as plants by the man who grows them for selling. He has a sponge garden in a shallow bit of sea; he cuts bits off the big sponges and sticks them to rocks, and they grow there just as a little geranium slip will grow into a plant with roots and flowers and all the rest.

But that sort of thing is not the usual way of 'having young ones.' It is uncommon in animals, and many plants have not this power either. The usual way for an animal to produce young ones is to have eggs, and the usual way for a plant is to have seeds. After all, the slip the gardener took from the geranium was just a piece of the parent plant with leaves on it already; and the cutting from the sponge was also just a bit of sponge already. But a hen's egg and a bean seed are something very different from a cutting. A hen's egg looks quite unlike any part of the hen from which it came; and it looks quite unlike the chicken that will come from it. And though a bean seed does not look at all like the bean plant that grew it, yet, if you put it in the ground, a bean plant will grow from it. So you couldn't distinguish animals from plants by any real difference in the power they have of producing young ones.

What *is* an 'animal' then ? An animal is a living being that, however like a plant it may look, can never make its own food before it feeds. The animal is usually much more energetic than the plant, and most animals move about (but don't let us forget about the sponge). The animal is usually much more sensitive than the plant (again I have to say 'usually' when I remember about the sponge).

CHAPTER III

THE ANIMAL'S BODY

PARTS OF A KETTLE – ORGANS OF A BODY – INSIDES – DIVISION OF LABOUR – A SINGLE CONTROL – THE LIVING STUFF – THE SAME ANIMAL BUT DIFFERENT

LET us go back for a moment to the cat and the kettle in Chapter I. The kettle is made up of four main parts. There is the vessel to contain water: then there is a spout, a handle and a lid. All these parts must be there if the apparatus is to be what we call a kettle (if there were no spout, for instance, you would call the thing a pot). Now each of these parts has a special duty to perform for the kettle. The main part holds the water to be boiled: the spout is for pouring out the water when it has boiled: the handle is for lifting the kettle on and off the fire: the lid covers the place where you pour the water in and it helps to keep the heat from escaping.

In the same way, it is possible to think of a living animal as a piece of apparatus. You can think of the parts of which it is made up, and then you can think of what they are for and how they serve the animal's body as a whole. The most obvious parts of a cat are a head, a body, four legs and a tail. On the head are a number of smaller, but very important parts, such as the eyes and the ears and the nose and the whiskers: these are the chief parts for coming in contact with what is outside the cat as it moves about in the room, and for giving it information of what is happening. And then, of course, on the head is also the mouth, by means of which the animal catches and eats its food. The legs have feet at the end of them, and toes on the feet, and claws on the ends of the toes. The chief duty of the legs is to move the cat about from place to place; but with the claws the cat can also fight its enemies. The legs are weapons as well as instruments for locomotion.

And so one might go on naming the parts of the cat, just as one named the parts of the kettle, and noticing that each has a special duty, or duties, to perform for the benefit of the whole animal. Such parts are called 'organs' when one is speaking of an animal. The leg is an organ of locomotion; the eye and the ear and the whiskers are sense organs, as I explained in the last chapter.

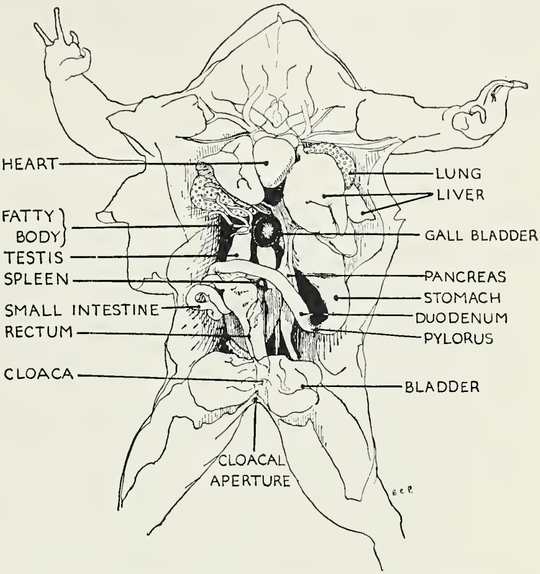
Now so far we have considered only the outside of the cat. But the inside has to be considered too. Many people have a horror of 'insides,' because all they ever see of these are the bits and pieces in a butcher's shop; and they get the wrong idea that the inside of an animal is just a hideous mess of blood and suet.

But the parts you see in the butcher's shop are looking quite unnatural, and it is not fair to think of the body like that. When the butcher chops up the dead meat, his knife cuts through the little pipes, the veins and arteries, in which the red blood travelled about inside the body when it was alive. And when these blood-vessels are cut, this lets the blood out, so that it spills about and gets smeared over everything. But if the blood-vessels were not cut, the blood would stay inside them and there wouldn't be any mess at all: and I assure you that the inside parts of the body, our own or the cat's or any other animal's, are arranged with the utmost neatness, and all packed together very tidily, without any mess.

If the body of a dead frog were opened without cutting the blood-vessels, you would be surprised, I think, to find how really pretty the inside of an animal can be. In fact, the inside of a frog is much more gaily coloured than its outside is. The liver is brown, the lungs are silvery, the heart is crimson and purple, the stomach and intestines are pink, the gall bladder is grass-green, the kidneys are red with orange spots, and near the kidneys are pointed streamers of fat coloured bright orange. And going to all these parts or organs are pure white threads called nerves, and red and purple tubes, the arteries and veins, containing the blood. It is not just the colours of the organs that are pretty: the neatness of the whole arrangement pleases one's eye, too.

The picture shows you how the organs look when the frog's body has been opened. The stomach and intestines are called the 'organs of digestion': it is into these that the food goes when it has been swallowed, and their business is to prepare the food for the rest of the body. The lungs are the 'organs of respiration'; they have to do with getting fresh air into the body and getting rid of foul air. The lungs also get rid of some waste water. The kidneys are the 'organs of excretion': their duty is to collect such of the water as does not leave the body by the lungs or by the skin and, in that water, soluble waste stuff made by the body. This fluid collected by the kidneys is stored in the bladder, and then drained off to the outside as urine.

The duty of the heart is to act like a pump, for driving blood through the blood-vessels, so that a steady stream is carried to and from every little part of every little organ. The red fluid that we call blood carries oxygen from the lungs and dissolved food from the stomach and intestines to every bit of the body, so that all are nourished: the blood also collects waste stuff from all these parts and takes this waste to the kidneys and to the lungs where it can be thrown out: and the warmth of the living body is distributed through it by the blood. These are only some of the things the blood does for an animal: but you can see at once what very important organs are the heart and the vessels that contain this precious fluid. If the heart stops beating, the animal dies. The heart is the one organ of the body that never, never rests as long as the animal lives. Even when the animal is asleep, the steady beating of the heart goes on, though more slowly than when the animal is awake and active.



A dead frog cut open to show the chief organs.

From Hentschel and Cook's *Biology for Medical Students* (Longmans, Green & Co., Ltd.)

But while it is convenient to do what we have been doing – to think of the animal as a piece of apparatus, I mean, and see what the various parts of it are and what each part does – I don't want you to get the idea that the animal's body is made of independent pieces stuck together. The parts of the kettle *are* independent pieces stuck together. It wouldn't matter to the spout if the kettle lost its lid. But it would matter seriously to the frog's stomach, for instance, if the lungs or the kidneys got damaged:

and they would none of them be of any use at all if the heart broke down. All the organs of an animal's body are necessary parts of a whole, and, so long as the animal is healthy, they work together smoothly. It is one of the most extraordinary things about a living animal that, however elaborate its parts are, the whole body is under one control. This control is exercised by the brain and spinal cord. We shall come back to this in Ch. XXIX.

And another very extraordinary thing is that, although the parts look so unlike one another as do, for instance, the lung, the eye, the stomach and the brain, and though they act so differently, yet they are all made of the same material. This material, if you see a bit of it alive under the microscope, looks like half-transparent jelly and not particularly interesting. You would never guess, just from the look of it, what it can do. The frog is all made of it: and everything the frog does it can do because of the magical powers of this stuff. You and I are made of it, and so is the cat and so is the geranium, and so is everything that is what we call 'alive.'

I wish there were an easy name for the living stuff. There isn't, so I have to use the name scientists have given it. That name is 'protoplasm': which is a short way of saying 'the fundamental material for forming living things.' My protoplasm is not exactly like your protoplasm, and human protoplasm is different from frog protoplasm and from cat protoplasm: and yet all protoplasm is made of water and a few very common chemicals, of which carbon, nitrogen, oxygen, hydrogen and sulphur are the chief. We know what protoplasm is made of, but we cannot make it. Even the cleverest scientists, though they have the carbon, hydrogen, nitrogen, oxygen and the other things all handy, cannot so join these together that the result will be protoplasm and alive. No man has ever yet made protoplasm except in his own body.

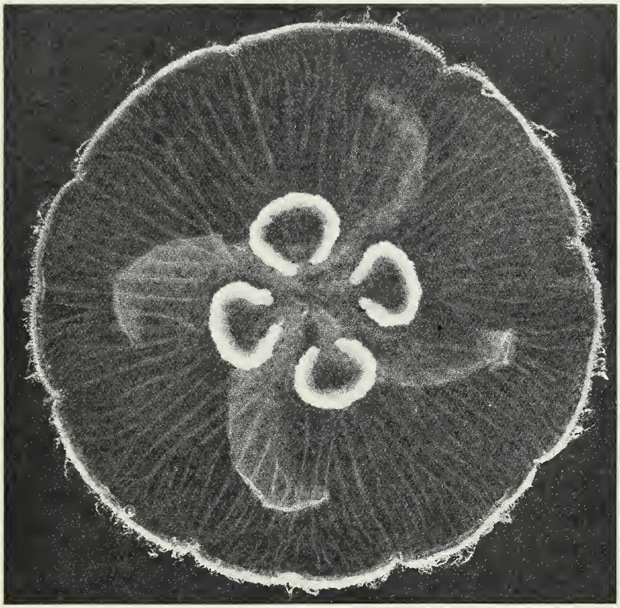
One of the important things about living protoplasm is that its chemistry is changing all the time; and since the animal's body is made of protoplasm, this means that the whole body is changing and changing as long as it is alive. Yet one feels that the animal is the same animal however long it lives. One might compare the living animal to a river. 'There is the River Thames,' you say as you drive across the bridge. You drive back across the bridge later in the day on your way home, and again you say to yourself, 'There is the River Thames.' But, in a way, it is *not* the same river you saw that morning: all the water you saw then has reached the sea by now.

CHAPTER IV

SKELETON AND MUSCLE

THE JELLY-FISH — THE SKELETON AS A SUPPORT — INSIDE SKELETONS AND OUTSIDE SKELETONS — THE SKELETON AS ARMOUR — THE SKELETON AS ATTACHMENT FOR MUSCLES — MUSCLE IS MEAT — WHAT MUSCLE IS FOR — HOW THE MUSCLES OF THE ARM WORK — 'INVOLUNTARY' MUSCLE — PARTS OF THE HUMAN SKELETON — ALL THE LARGE ANIMALS HAVE THE SAME SORT OF SKELETON

A LARGE body made of nothing but soft protoplasm would be quite unworkable on land. It might be all right in the sea, especially if it were content to drift, for the sea water would buoy it up. In fact, I can think of fairly large sea-animals, jelly-fish, which are just floating umbrellas of protoplasm and water: some jelly-fish measure several feet across.



Photo, Exclusive News Agency

An animal with no skeleton. Jelly-fish seen from above.

(Notice that the outline of the body is dented at eight places. There lie the jelly-fish's ears.)

On land, completely soft animals are rare. Slugs and earthworms are the best examples I can think of, and these are lowly, inconspicuous creatures, living under stones or in burrows in the earth.

All the large animals that live on land have to have their bodies stiffened in some way if they are even to stand up, let alone move about on legs. For the air will not buoy up a soft body as the sea does.

The hard parts acting as supports for the soft parts are what we call the skeleton. The hard parts of the animal body are made by the protoplasm, but they themselves are not living.

There are two ways of wearing a skeleton. It may be worn inside the soft parts, or outside them. The first way is our way, and the cat's way, and the frog's way, and the bird's way: in fact, it is the way of all the animals that have two pairs of limbs. The other way is used by the insects and the spiders, and by the lobsters and crabs and all their relations. Animals like oysters and snails also have their skeleton outside.[1]

When the skeleton is inside, like ours, it is made either of gristle or of bone. Gristle is a stiff, half-transparent stuff, firm but bendable. Bone is composed chiefly of limy mineral matter: it is much, much harder and denser and stronger than gristle, but it is not bendable. All the land animals of any size have bony skeletons when they are full-grown; and as the animal gets older, these bones become more packed with mineral and so get heavier.

When the skeleton is outside, it is usually made of a brown stuff like horn. In lobsters and crabs, mineral matter, lime, is mixed in with the horn.

An outside skeleton does more for the soft parts than just support them: it also covers them and protects them. An outside skeleton is armour as well as scaffolding. Think of beetles and cockroaches and earwigs if you want to get a picture of the glistening coat of armour that is the insect's skeleton. And if you have a good picture of an insect in your mind – I mean, if you have really looked at the insect and noticed carefully how its parts are arranged – you will realise that this armour is not just one solid piece equally thick all over the insect's body. If the insect were encased in a stiff, thick-walled tube, it wouldn't be able to bend its body: it would be quite rigid.

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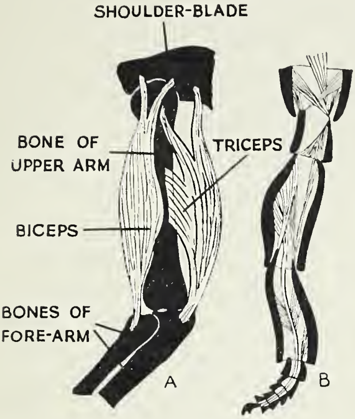
[1] There are one or two animals which have both inside *and* outside skeletons at the same time. The tortoise, for instance; and the armadillo.

So that the insect can bend its body, the armour is jointed: thick parts alternate with thin parts, and bending is possible at the places where the armour is thin. Each of the six legs is also clad in this plate-armour, which is very elaborately and neatly jointed at the knee and ankle and right down the little feet.



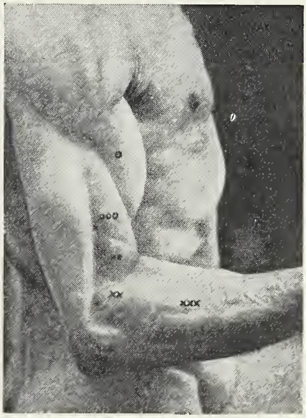
Muscles in relation to skeleton (A) in human arm and (B) in insect's leg.

From Hogben's *Principles of Animal Biology* (Christophers)

This brings me to yet a third reason for having a skeleton. And that is – to make it possible for the animal to move quickly by means of jointed limbs. The skeleton acts as something firm for the muscles to be fastened to; and it is the muscles that are responsible for all movement of the body's parts.

Before I can explain how the skeleton is used in making movements, I must say something about this stuff called muscle, this flesh or meat. Because that is what muscle is. Whether you call it beef, mutton or pork, the lean part of meat is muscle – of ox, sheep or pig.

A muscle is made up of very fine pink threads of protoplasm bound together in bundles. These threads have the power of being able to shorten and thicken themselves. As all the threads in the muscle are doing this at one time, the whole bundle swells out in the middle, but gets shorter. When this happens, we say that the muscle 'contracts.' After the muscle has contracted, it presently does the opposite thing: it 'relaxes.' Which means that it goes back to the original long, thin shape.



A strong man lifting a weight with his right hand. O is his biceps muscle bulging out.

From Hill's *Living Machinery* (G. Bell & Sons, Ltd.)

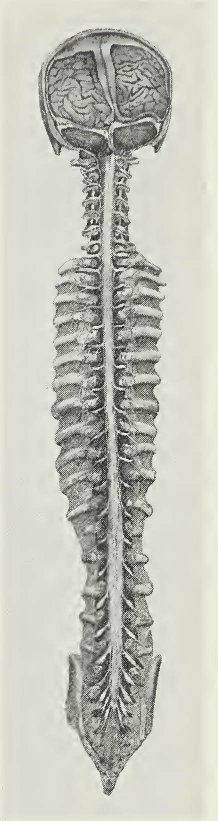
Suppose now that there are two movable rods and one of these is fastened to each end of the muscle: when the muscle contracts, the effect will be to pull the two rods towards each other. If one of the rods is held steady, however, and the other one is hinged to one end of it by a sort of joint, the effect of the muscle's contracting will be to pull the free end of the movable rod towards the fixed rod. In fact, you get a state of affairs that you can compare with that in the lower picture on p. 15, where the rods are the bones of the human arm. The muscle is the biceps; and, in contracting it is helping to pull the hand end of the forearm nearer to the shoulder. (If you slowly raise your left hand – palm-side up – towards your shoulder and keep your right hand on the upper part of your left arm as the forearm moves, you can feel your biceps muscle swelling as it shortens.) The muscle is fixed to the bones by glistening white cords called sinews or tendons: these cords are very tough and inelastic, and they cannot contract. At the upper end, the biceps muscle has two of these tendons to fix it to the shoulder: 'biceps' means two-headed.

When you straighten your arm again, the biceps relaxes and ceases to bulge out. But this is not enough to straighten your arm; by relaxing, a muscle cannot push a bone back into place. What happens is that another muscle, lying up the back of your upper arm, now contracts in its turn: the lower tendon of this second muscle passes over the back of your elbow joint and is fixed to the skeleton of the forearm. As this muscle, the triceps, contracts, the effect will be to pull the forearm in line with the upper arm, so that the limb is once more straight. Such muscles always work opposite one another like that, in pairs: one bends a limb at a joint, and then its partner on the opposite side pulls it back again. You can easily see now what I meant when I said that limbs could not be worked by muscles unless they were stiffened and jointed: there must be something firm, either inside the limb or outside it, for the muscles to get a pull on, and there must be joints at which the bending can take place.

It is not only when a part is to be moved that the muscles connected to it contract. Even to keep your body erect while you are sitting, and to keep your head from drooping over to one side or down on to your chest, the opposite sets of muscles all the way round your body and round your neck are contracting just enough to counterbalance one another and hold you up.

These muscles connected with the skeleton are sometimes called the 'voluntary' muscles – the muscles that can be *willed* to contract. I don't mean to say that you think all the time about the contraction of your muscles, and order them to do this or that. As a matter of fact, most of our walking and moving is such a fixed habit that we leave our muscles to get on with the job. But you can interfere if you choose: you don't *have* to go on walking unless you want to.

I mention this, because there are certain muscles in the body over which we have no such control. These muscles are not attached to the skeleton, and they are not for moving the body and limbs. I am thinking, for instance, of the muscles of the heart: it is the contraction of these muscles that makes the heart continue to pump blood round the body. Another example would be the muscles in the wall of the stomach and intestines: the contraction of these keeps the food moving along. We cannot interfere with what these '*in*voluntary' muscles do: they are quite out of our control. Which is just as well! For if you interfered with the working of your heart muscles, you would be dead in no time.


Rüdinger

Back view of the brain and spinal cord lying in the shelter of the skull and backbone.

From Hill's *Living Machinery* (G. Bell & Sons, Ltd.)

Now I come back to the skeleton, the inside skeleton of a human being. I am going to describe it very briefly; just enough to help you compare with it the skeletons of other animals built on the same plan as ourselves.

The first thing that is special about it is the backbone. Right along the middle of your back runs this very remarkable support. It is not an undivided, solid rod of bone: if it were, you would be unable to bend your body, however hard your muscles contracted, and you would feel as though you had a poker up your back. It is made of separate little bones, called vertebræ, set one on the top of the other. If you pile a lot of empty cotton reels one on top of the other, this gives you some notion of the arrangement of the vertebræ in the backbone. I chose a reel rather than just any short cylinder of wood, because through every reel there runs a short tunnel. And that's what you find in the parts of the backbone: each has a tunnel running through it. For the backbone serves as skeleton in all the three ways: it acts as a flexible support for the body; it serves for the attachment of muscles that bend the body this way and that; and it protects a very important, very delicate organ. The organ that is specially protected by the backbone, passes along the tunnel that goes from end to end through the small reel-like bones that make this part of the skeleton. It is called the spinal cord, and, with the help of the brain, this soft organ takes charge of all the body does. That is why it is so precious and why it is specially protected inside the backbone.

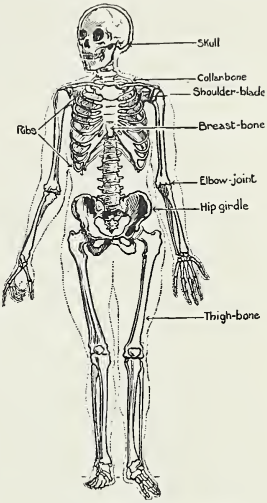
At the head end of the backbone is a large, rounded box of bone, called the skull. In it the brain is protected, and to it are attached the jaws where the teeth are. Special, hollowed-out parts of the skull lodge the eyes and the ears.

An arm looks different from a leg; but arms and legs are built on the same plan really. The upper part of the arm corresponds to the thigh, the elbow corresponds to the knee, the forearm to the lower part of the leg, the wrist to the ankle, the palm of the hand to the sole of the foot, and, of course, the fingers correspond to the toes. When you look at the skeleton that supports these parts, you find a close resemblance between arm-bones and leg-bones. In the upper arm and in the thigh is just one bone: in the forearm and in the lower part of the leg are two bones placed side by side: in wrist and ankle are two rows of very small bones arranged like bricks in a bit of wall: and then the palm and the sole are supported by five slender bones, each of which ends either in a two-jointed piece (for the thumb or the big toe) or a three-jointed piece (for a finger or one of the smaller toes). The proportions of these bones are different in the leg from what they are in the arm, because the limbs are used differently; but the general plan of the skeleton is the same.

The skeleton of the limbs is connected to the backbone by means of bones arranged to make what are called 'girdles.' The shoulder-girdle in the human being is made of two bones on each side. You know where your collar-bones lie? Feel along one of them with your finger. It passes from the bottom of your neck out towards the top of your arm, and it holds your shoulder out nice and square. The other bone of the shoulder-girdle on each side is called the shoulder-blade. The shoulder-blade runs from the top of your arm towards the middle of your back, where it is connected to the backbone by muscles and other soft parts. Corresponding to the shoulder-girdle, which supports the arms, is the hip-girdle, which supports the legs. It is a much more solid thing than the shoulder-girdle, and is shaped like a sort of basin. When you sit down, you are sitting on this bony basin. There is so much muscle and fat in this part of your body that you cannot easily feel the shape of the skeleton with your hand as you can feel the shape of the shoulder-girdle. But in the picture you see the hip-girdle in position on the skeleton. Not only does it attach the legs to the backbone; it also protects and holds up in its basin the soft organs inside the lower part of the body. This lower part of the body is what is called the 'abdomen.' People usually call it the stomach: but really the stomach is just one of the organs lying inside the abdomen.

The upper part of the body is called the chest. The organs in the chest are the heart and the lungs and the largest of the blood-vessels. These are specially protected in a kind of cage of bone made by the ribs. The ribs shelter the chest organs, and they also act as attachments for the muscles that move the chest when we pump air in and out of our lungs in breathing. The ribs touch the backbone behind: in front, the bony cage is completed by a middle, jointed piece called the breast-bone.

I have described the human skeleton because you can easily feel where so many of the parts are in your own body. But all the hairy animals (the mammals, as they are called) have their skeleton made on just the same plan. So really also have the birds and the reptiles and creatures like frogs and newts. The fishes have a different limb-skeleton; but they are like us and the others in having a skull, and a backbone made of vertebræ. To describe ourselves and all these animals, the word 'vertebrate' is used: which means 'having a backbone.' The other animals (those with no skeleton at all or with an outside skeleton) haven't got a backbone: and the word to describe this state of affairs is '*in*vertebrate.'



Drawn by L. R. Brightwell

Human skeleton.

From Andrade and Huxley's *Science and Life* (Basil Blackwell)

Now that you have got the general plan of the vertebrate skeleton clear in your mind's eye, I can go on to compare the different ways in which animals move about and use their limbs.

CHAPTER V

GETTING OVER THE GROUND

WHY ANIMALS MOVE ABOUT – LIMBS OF A DOG – THE HORSE HAS ONLY ONE TOE – THE CLOVEN HOOF – FLAT FEET AND TOE-WALKING – PRETEND TO BE A NEWT – AND THEN A RABBIT – GAIT – THE FROG AND THE KANGAROO – THE BIRD'S FOOT – AND THE MONKEY'S

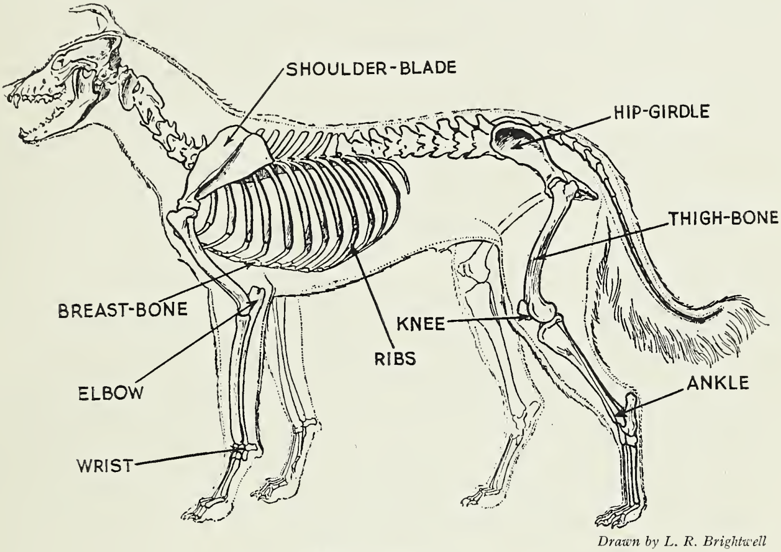
THOUGH, as we have seen, it is not the most important difference between them, certainly one of the things that distinguishes animals from plants is their power of movement. Animals move, and they move *about*. They move about because they have to go in search of their food, and in search of their mates. When a sheep has cropped all the grass immediately in front of him, he moves on to the next patch: when a lion gets hungry, he goes out to hunt for a zebra.

We human beings walk over the ground on our two hind limbs. But not many animals can do that – except, of course, birds and some of the animals, like the kangaroo, that jump. Nearly all the vertebrate animals go on all-fours when they are on land. To stand upright on two limbs takes some doing: it is much more difficult to keep the balance that way, and the muscles take a lot of educating. Every baby has to learn the balancing trick, and at first it goes on all-fours like the other animals. The human body, however, is really built for two-legged walking, and gradually the baby learns.

But while our way of walking and the dog's or horse's or rabbit's way of walking may seem so different, the difference lies in the way the limbs are held and used, and not in the plan of the limbs themselves. If you compare the skeleton of a man's arm with the skeleton of a dog's front leg, you find the same parts – one long bone in the upper arm, two bones from elbow to wrist, then the little wrist-bones, and lastly the bones of the palm of the hand and of the thumb and fingers. The parts are the same in the man and the dog, although a different use is made of them.

It is the same with the man's leg and the dog's hind-limb. From the hip to the knee runs one long thigh-bone: from the knee to the ankle, two bones: then come the small bones making ankle and heel: and lastly, the foot and toe-bones. The dog has lost its big toe – it has only four toes on the hind-foot: otherwise there is no real difference between the skeleton of the dog's foot and ours. It is true that the last joint on each of our fingers and toes carries a nail, and the dog's toes have claws: but nails are just flattened claws that don't go so far round the tip as a claw does.

Now compare the legs of a horse with those of the dog. The picture on p. 23 will help you. At first it looks easy. You see the thigh-bone at the top; and there, if it were a picture of the fore-leg, you would find the upper arm bone. But below the knee and below the elbow of the horse there is only one bone instead of the two you would expect. And then, below the wrist and ankle bones, comes the real puzzle. Below the wrist and the ankle the horse has just one rather long, upright bone, with three smaller pieces beyond it. Now it is here, below the wrist and the ankle, that we should expect to find the hand with its fingers and the foot with its toes. Well, that's just what this *is*. The horse has only one finger on its hand and only one toe on its foot: it has lost all the other digits. (I am going to use that word now – 'digit' – because it means either a finger or a toe and saves me using the two words so often.) You remember that the dog had lost its big toe; and its thumb, as you can see in the picture,



Drawn by L. R. Brightwell

Skeleton of a Dog.

From Wells, Huxley and Wells' *Science of Life* (Cassell & Co., Ltd.)

has got very short. The horse has lost everything but the middle digit in hand and foot, and these remaining ones have become very large and strong. The nail, or claw, or whatever you like to call it, gets immense in the horse and is known as the hoof.

I wonder whether you have ever noticed that the feet of sheep and cows end in a different sort of hoof from the horse's hoof ? The hoof in these animals seems to be split along the middle. But that is only what it looks like. The fact of the matter is that the sheep and the cow have not lost so many digits as the horse has. They have two digits on each foot, instead of just one. The digits that remain are the third and fourth; and what looks like the split in the hoof is the little gap between the ends of the two fingers or two toes, each of which has a small hoof of its own.

The pig also has 'split' hoofs: but the pig has lost even fewer digits than the sheep has. The pig still has its fifth toe and finger complete, so that makes four to each limb. Only the thumb and the big toe have quite disappeared. The second and fifth digits, however, are shorter than the middle two, and they scarcely touch the ground except when the pig is walking over soft, muddy stuff into which its feet might sink. Pigs often do that, you know; so the side-toes come in very useful then, for they spread out a bit and make the foot broader to walk on.

You can use your own hand to make this clearer. Put the tip of the middle digit on the table in front of you, keeping the finger and hand upright. Tuck the thumb and all the other fingers back into the palm. That gives you an imitation of the horse's foot. . . . Now put the tip of the fourth digit (the ring finger, it is sometimes called) down beside the third one, and pretend that they are the same length. Your hand is standing on two fingers and you are imitating the cow's and sheep's foot. . . . Next, let the second and fifth digit (the index and little finger) hang down beside the other two, and pretend your fifth digit is as long as the second one (still keep the thumb hidden). That gives you the pig's foot.[1]

You see what I mean ? By taking away the big toe or the thumb, and then by taking away the second and fifth digits, and lastly by taking away the fourth digit also, it is possible to get from the plan of a foot or a hand like a man's to the plan of a pig's, and from there to a sheep's, and from there to a horse's. You add nothing new: please notice that. All you have to do is to make some parts smaller and smaller, and some parts larger and stronger. The main plan of the limb is the same all through: but the proportions of the parts are very different. And the proportions of the parts are different because the limbs are to be used in different ways, for different sorts of walking.

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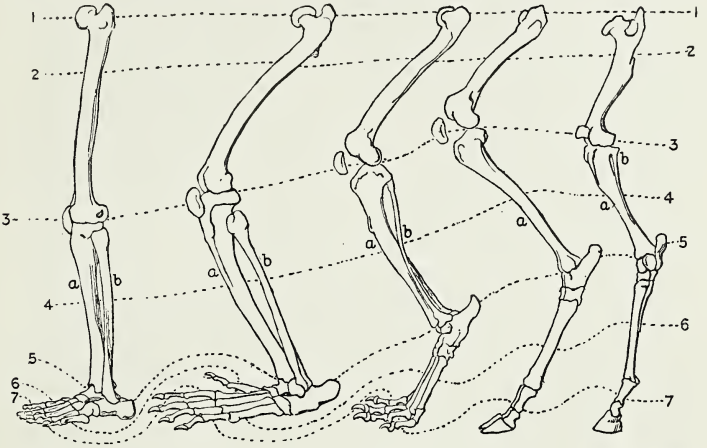
[1] It would be a good idea if you bought sheep's and pig's 'trotters' from the butcher, and cleaned off the skin and flesh so that you could see the bones clearly. Then compare the two kinds. There's another difference between them that I haven't mentioned; I wonder if you could find out for yourselves what it is ?

Now let us consider the way in which the foot is placed on the ground. When you and I walk, we place the whole sole of the foot on the ground, heel first and toes last: and everything touches the ground, except the instep arch and the little cracks between the toe- and sole-pads.



After Le Conte

Hind-limb skeleton of man, monkey, dog, sheep and horse. The dotted lines pass through corresponding parts in the five limbs: 1, hip-joint; 2, thigh-bone; 3, knee-joint; 4, bones of leg; 5, ankle-joint; 6, bones of foot; 7, bones of toes.

From Romanes' *Darwin and after Darwin* (Longmans, Green & Co., Ltd.)

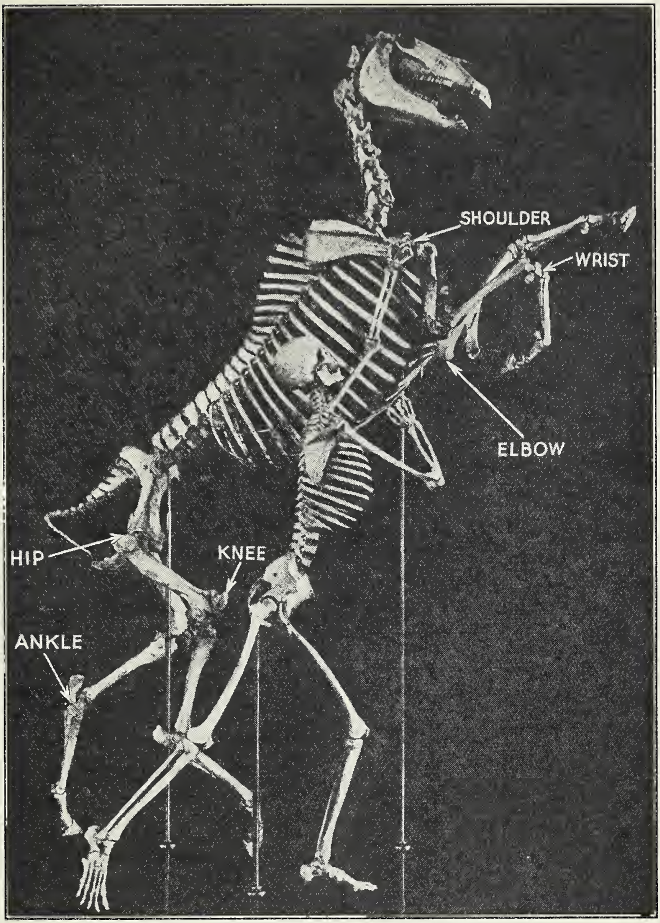
But when we run very fast, we run more on our toes – on the 'ball' of the foot – with the heel in the air. The rabbit rests with his hind-feet almost flat on the ground; but, as he bounds away, he also raises his heels. And his front paws always rest much more delicately upon the ground, with the wrists high up and only the fingers touching the earth. Except when they are sitting, the cat and dog keep both front *and* hind feet in this position, with wrist and ankle high and only the fingers and toes on the ground.

The horse and the other hoofed animals go one better still, and they walk on the very *tips* of their few remaining digits. The foot, as we have seen, is long and narrow in the horse, so this tip-toeing throws the ankle and wrist very high; and that is splendid for fast running over hard ground. You know what a 'broken-kneed' horse looks like ? Well, now you see that the bad joint in that front leg of his is not his knee, nor even his elbow; it is the horse's wrist. The broken-kneed horse is a horse with weak or damaged wrists. Look at the skeleton of man and horse (p. 25) and notice carefully the position of the horse's wrist, elbow, ankle and knee.

For us it would be too exhausting to walk about all the time on our tip-toes – though ballet-dancers are trained to do it. It would be exhausting, because we are built to go on two legs only and to stand upright; and so we need a broad base, if we are to keep from toppling over. But an animal whose body is held up at four points is in a steadier position than we, and can afford to go on tip-toe. The racehorse on his single tip-toes can run forty-five miles an hour; and that is as fast as most railway trains.

Next I want you to look at those pictures on p. 27, and especially at the one marked D (picture C is supposed to be a side-view of the same animal). The newt is an animal which has its limbs placed rather like that. When the newt is on land, the long body practically rests on the ground, but is held up at four points by the limbs. And as they hold up the body for walking, the newt's limbs stick out from its sides, elbow out and knee out, with the hands and feet planted flat on the ground and the first digit towards the animal's head (the positions of the hand and foot show best in C). Now imagine you are a newt; and, with your right arm, try to imitate the position of the limbs in pictures C and D. Make three movements of it, as though you were drilling. *One*, hold your right arm straight out from the shoulder, quite level; straight out from the side of the body. *Two*, bend your arm sharply at the elbow. *Three*, bend your hand back towards the elbow as far as it will go, keeping the thumb pointing upwards. . . . Now you've got to imagine that the ground is under the palm of your hand. . . . That is the position of the newt's right fore-limb as it walks. Its three other limbs would of course be in the same sort of position.

The animal that walks with its limbs in this stuck-out position is usually very awkward on land. It gives a waddling sort of movement and the body trails a bit on the ground. Animals like that, newts and crocodiles, are much better movers in the water. When they are on land, you can see that their limbs have two things to do; first, they have to lever the body along, and, second, they try to hold it up from the ground. For if the



Skeletons of man and rearing horse.

Mounted by S. H. Chubb in the American Museum of Natural History and reproduced by courtesy of the late Henry Fairfield Osborn.

body trails, there is bound to be a lot of friction, and that interferes with swiftness; and is also rather uncomfortable for the animal, I should think. So you find that in animals which spend all their time on land and move along quickly, the limbs are longer in proportion than they are in the newt and the crocodile, and the body is lifted up; sometimes, as in the horse, it is lifted very high off the ground.

But notice that in such animals another thing has happened, besides the lengthening of the limbs. The knee and the elbow have been brought against the side of the body. The knee and elbow no longer stick out, and the hand is turned so that the thumb side lies towards the middle line of the body. Look at pictures E and F and you'll see what I mean. These are supposed to be side and front views of some animal like a dog.

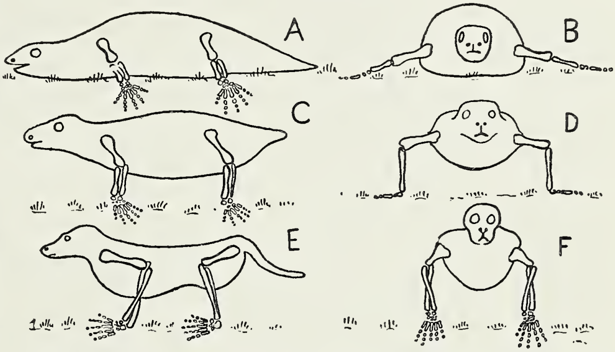
See if you can imitate with your right arm what has happened. Get your arm back into the newt-position, as in picture D. Now, keeping the arm quite steady, bring the elbow down against your side. Then turn your hand so that you look down on the *back* of it. Your arm is now in the position of the dog's front leg, or the rabbit's, or that of any other of the hairy, fast-running creatures. But in the last few minutes you have done some things that no rabbit or dog could do: and one of these is that movement of the hand. A rabbit's hand is fixed in the position you have deliberately taken up: a rabbit cannot turn its hand to and fro as you can. It doesn't need to. The rabbit's hands are for running with and digging with: and not for climbing with or picking things up.

What I have been telling you about the position of the limbs leads on to the question of gait, the kind of walk an animal uses. Like ourselves, land animals use their walking limbs something in the way a man uses a pole to punt a boat along, pushing off with it from the ground. (*See* picture on p. 56.) We and the rabbit and the dog and all the others lever ourselves over the ground with our legs. . . . A running dog twinkles along so fast that it is difficult to see in what order he puts his feet down. But slow-motion films have helped us there, and we know now that, in ordinary running, a dog takes his feet up and puts them down in the following order – right fore-foot, left hind-foot, left fore-foot, right hind-foot. In galloping, however, the dog puts down both his front feet almost together; and then both his hind feet almost together. It's the same with a horse; in ordinary running and galloping, the horse uses his limbs as a dog does. In *very* fast galloping by a greyhound or a horse, all the feet are off the ground at the same time.

You may have noticed that some of the big animals have yet a different gait. This is called 'ambling.' The elephant and the camel are good examples. In ambling, both the right legs are moved almost together, and then both the left legs. Horses don't do this naturally, but they can be trained to amble. Horses for ladies to ride on used to be taught ambling, because it makes riding very smooth.

All this time I have been telling you about animals that have the usual sorts of four-legged walk. But there are some that get over the ground by jumping – creatures like the kangaroo, for instance, and the frog. In all these, the hind pair of legs is much longer and stronger than the other pair; and when the animal is at rest, these legs are kept bent. Then they are suddenly straightened, and the animal's body is jerked off the ground in a forwards direction. The kangaroo's great, strong tail helps in the push-off. The frog has no tail, and so depends entirely on the long hind-legs for the leap. It is a tremendous leap. A small frog will easily take a jump six times its own length, if it is alarmed and trying to get away in a hurry.

As for birds, they do not use their front limbs for walking at all. They walk on two legs, as we do. But they are toe-walkers, and the ankle is high off the ground. (*See* picture on p. 48.) The bigger birds all walk or run; but the smaller birds may either run, or else they hop – bounding along on the two feet together. Birds never have more than four toes. I wonder if you have noticed that the parrot's toes are arranged differently from other birds ? Two toes are turned forward and two are turned back. This has to do with the parrot's using its feet like hands, for picking up food and for climbing about on the branches, where the arrangement of the toes gives the foot a good grip. But the climbing foot you know best, of course, is the monkey's. In the monkey, not only is the thumb set apart from the fingers, as in ourselves, but the big toe also is set apart from the other digits. This gives a splendid grip on the branch where the animal is climbing.



Going on all fours. A and B, side and front views of an animal whose body still rests on the ground and whose limbs are used for rowing it along. C and D, the same views of an animal whose limbs now lift the body off the ground as well as move it along. E and F, the same views of an animal like a dog, where knee and elbow now lie against the side of the body.

From de Beer's *Vertebrate Zoology* (Sidgwick & Jackson, Ltd.)

CHAPTER VI

HOW ANIMALS MOVE IN WATER

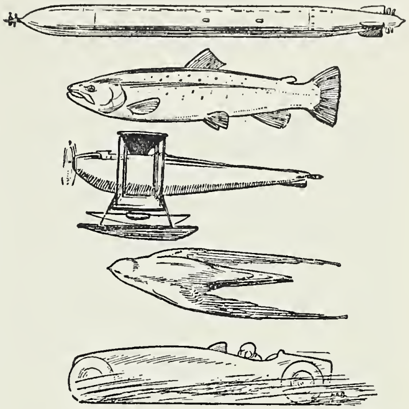
STREAM-LINING – TAIL AND FINS – SCULLING – THE FISH'S GAS-BAG – THE WHALE IS NOT A FISH – WHAT MAKES THE WHALE LOOK LIKE A FISH – THE TURTLE'S TRUDGEON STROKE – A USE FOR WEBBING

MOST land animals can swim if they are forced to. Even pigs, which are supposed to be such bad swimmers, can swim quite a long way though they make such a fuss about it; and the tiger is a very good swimmer, I am told. But the pig and the tiger are land animals really, and so it is on land that they are at their best.

Then one can think of some kinds that can get along on land all right, although they are really most at home in the water; ducks and frogs and turtles, for instance. And lastly, there are the fishes and the whales, which can't live out of water at all.

I shall begin with these completely water animals – the fishes and the whales. Look at the salmon in that picture called 'stream-lining.' When I say 'shaped like a fish,' you know just what I mean; but it isn't easy to describe this shape in a few words. The fish's body is thickest in the middle and narrows gracefully to head and tail: there is no neck separating the head from the rest. Have you noticed that the man who designs a torpedo or the body of a racing motor-car or of a fast hydroplane, is copying the fish shape? And the fast-swimming fishes are usually rather flattened from side to side: I mean, they are narrower than they are high.

What is the 'idea' of this shape, and why does the man copy it when he is making a fast-travelling machine? The full answer would take a long time and some mathematics. But it is not difficult to realise that when a body is moving fast through the air or through the water, it has to push its way along and overcome some resistance. Water is thicker stuff than air, and the body that moves through water has to push harder. You know how much more difficult it is to wade in water than to walk in air on land. You have to push hard with your legs against the water to get along, and your feet feel heavy and bound, as though you were in a bad dream. Yet fishes dart about under water as though it were the easiest thing in the world. A salmon will swim steadily at the rate of seven miles an hour, and he can get up a speed of twenty-five miles an hour when he is frightened. Twenty-five miles an hour is a tremendous pace for an animal of that size moving through such thick stuff as water.



Drawn by L. R. Brightwell

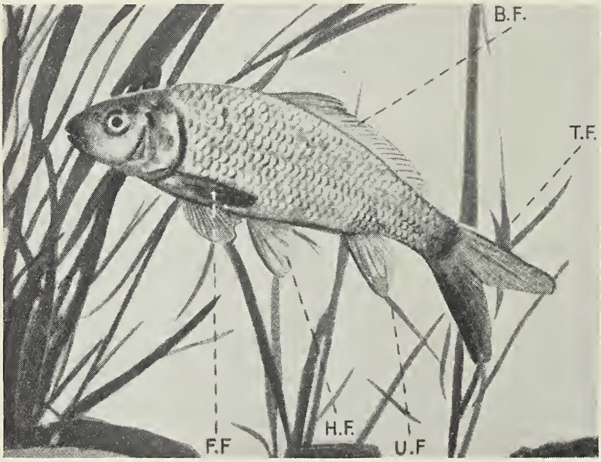
Stream-lining. A naval torpedo; a salmon; a hydroplane; a swift; a racing motor-car.

From Andrade and Huxley's *Science and Life* (Basil Blackwell)

One explanation of the swift swimming by the fish lies in the shape of the body. The fish shape cuts through the water and overcomes the resistance more easily than any other shape would. It offers as little surface as possible to the push of the water in front, and the water glides off the smooth curves of the sides. We say that a fish's body is 'stream-lined.' A boat also is stream-lined, so far as the hull is concerned. Think of the different sorts of boats. Think of the fast boats, like canoes and the boats men row races in – how narrow they are in comparison with their length. Then think of a slow-moving boat like a punt or a barge, and note how broad it is in proportion: moreover, the slow-moving punt is not sharply pointed in front and behind like the fast boat or the fish.

There is another thing to bear in mind, though, about moving in water. While it is true that water is harder to move in than air, it is also true that water is easier to keep up in than air. The body of the swimmer tends to float; it is supported by the water. Water is much more buoyant than air. So, although the animal has to cut his way through water with more effort, he is held up by the water and he needn't waste his strength in trying not to sink down. The water animal can put most of his strength into moving forward.

On p. 30 you see a picture of a carp, the kind we call a goldfish. You will easily understand that if the stream-lined body of the goldfish is to glide forward easily, its surface should be as smooth as possible. Large, jutting-out limbs would tend to offer resistance to the water and act as brakes. The fish's limbs are actually very small in proportion to its body. The limbs of a fish are soft, bendable folds. We call them the 'paired fins.' The front pair (marked F.F. in the picture) lie near where the fish's neck ought to be, low down and just behind the lid that covers the gills: the hind pair, still smaller (marked H.F. in the picture) lie even lower on the body. When you watch a live goldfish in its globe, notice that the paired fins are hardly ever still. They move up and down, and back and forth, and they make little, twisty movements; they open and close; sometimes they are moving together, sometimes turn about. But when the fish darts forward, its limbs are tucked back against the side of the body, out of the way. The goldfish does not use these fins for swimming. The limbs seem to be for balancing in the water, so that the fish doesn't tilt over on one side; and they probably help a bit with the steering.



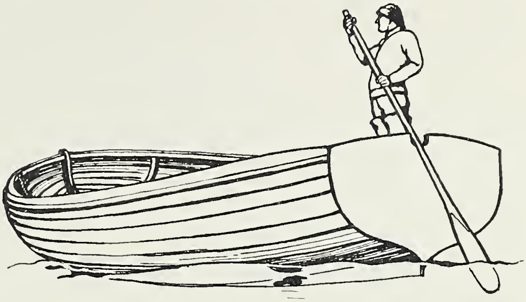
Carp. B.F., back fin. T.F., tail fin. U.F., under fin. F.F., paired fore fins. H.F., paired hind fins.

From Johnson's *Freshwater Fishes and how to identify them* (Epworth Press)

What moves the goldfish forward is not its limbs, but its tail. The fish's tail is the propeller, and, as in a steamer, the propeller is at the back of the boat – in the stern. The tapering hind-end of the fish, which we call its tail, has a delicate fin round it, very like the stuff of the paired fins – an almost transparent fold held up by thin, bendable rods of bone.

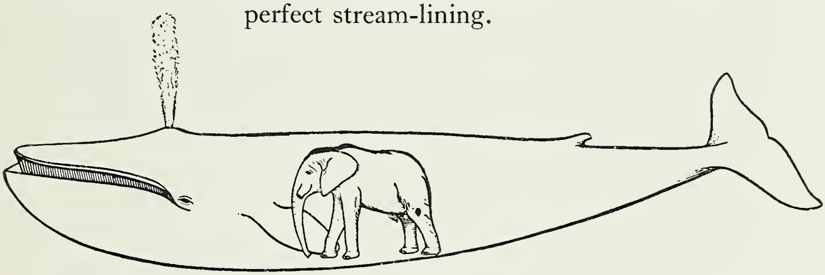
When a man is sculling, he stands at the back of the boat and he has a single oar; he swishes the oar to and fro with a twisty movement, and the boat shoots forward. The fish sculls with its tail, you might say; for it swims along by swishing its tail from side to side at the stern end of its boat body. But the movement is not just a stiff, side-to-side turning: there is a screwing movement as well. Nor is the tail-fin a hard, stiff thing like an oar-blade: it can be opened and shut like a fan, and can be thrown into changing curves.

You will also have noticed that there is a single fin along the animal's back (marked B.F. for back-fin), and another, smaller one (marked U.F. for under-fin) below the body just in front of the tail. Some fishes have more than one back-fin: if this were a haddock, there would be three. And a haddock has two under-fins, instead of just one. These back and under fins are constantly being spread out and then folded down, and wavy movements run along them. Probably they help with the balance, something like the centre-board keel of a yacht.


Drawn by B. Phillipson

Sculling. The fish uses its tail this way.

Now look closely at the surface of the fish's body, so smooth and glistening. It is covered with a close-fitting coat of scales. Fish-scales are very thin, transparent plates of bone, which overlap one another like the slates on the roof of a house. Notice that the edges of the scales all point backwards towards the tail. If the scales pointed forwards, water would push in under them as the fish swam, and they would be prised up; and that would interfere with the perfect stream-lining.


A whale and an elephant drawn to the same scale. (Notice that the whale is breathing out moist air from its nostrils.)

From Lull's *Organic Evolution* (by permission of The Macmillan Company, publishers)

A very interesting thing about most fast-swimming fishes is that they carry a sort of lifebuoy inside them. Just under the fish's backbone is a long sack, with tough, leathery walls; and this sack is filled with gas. Having this gas-bag inside helps the fish to stay swimming at just the depth in the water that the animal finds convenient. If the fish has to rise nearer the surface, it puts more gas into its bag: if it wants to sink lower, it takes some out. If a fish is dredged quickly from very, very deep water, its body may burst like a balloon when it comes to the top, because the gas in the bag expands when the great weight of water overhead is suddenly removed.

Among the world's best swimmers is the whale. The whale is the largest animal in the world – far, far bigger than an elephant. Some whales weigh as much as three railway trains put together. An animal as large as that couldn't go about on land; it would be crushed by its own weight. But it can live quite well in the sea, because the water buoys up even that tremendous body. The whale has the same stream-lined shape as a fish; but it isn't a fish, though it looks very like one. (*See* picture on p. 31.) How do I know that a whale isn't a fish? . . . Well, for one thing, I know that the whale has to come up to the surface every now and then for a breath of air. A fish doesn't do that. When a trout comes to the surface, it is coming for a fly, not for air. A whale has lungs, as we have, and it breathes air through its nose the way we do. Fishes don't breathe air.

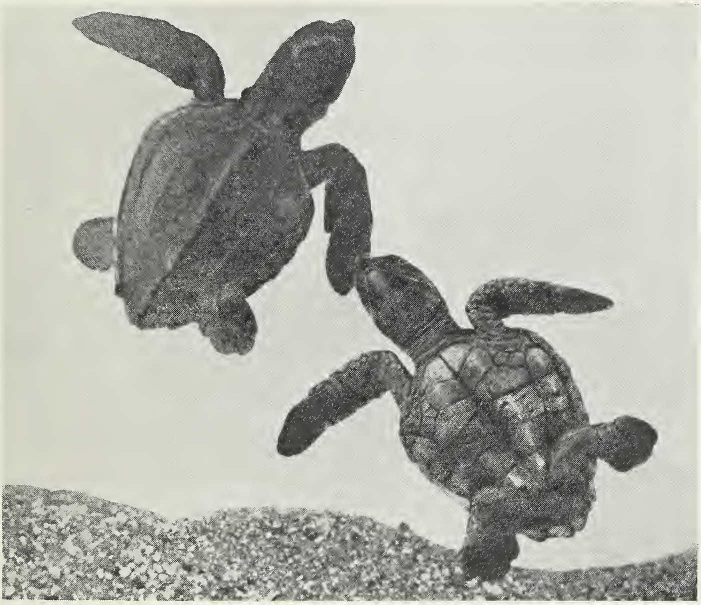
But there are other differences besides the breathing. The fin on a whale's tail runs cross-wise, not up and down like a fish's. And the whale has only one pair of limbs, the front pair. They look like rather thick, solid fins; but if you took the skin and flesh all away from them, you would find that inside they are not like a fish's limbs at all. The whale's fin has inside it the very same bones that are in your own arm or in the dog's front leg. You see, the whale really comes of a race of land-animals that have taken to living in the sea altogether. It has lost its hind-legs, and has come to look like a fish because the fish shape, the stream-lined shape, is so good for fast swimming. But the whale's lungs and the bones inside its paired fins give it away completely to those who know.

Unfortunately one doesn't get much chance of watching turtles swimming. But there is a big tank of them at the London Zoo, and when I was watching them there the other day, I was fascinated by their movements. And I want to say something about that here, because the turtle is one of the backboned swimmers that row under water with their limbs, using them like oars. This is different, you see, from the fish, who sculls with his tail.

A turtle is a big, flattish sort of tortoise that has given up living on the land and has taken to spending most of his time in the sea. Because the turtle's ancestors were land animals, he has lungs, and so he has to come to the surface for a breath now and then, as a whale does. As you might expect, then, the turtle's limbs are built on the same old plan that we find in all the true land animals with backbones. But the turtle's limbs are not very good for walking with. The toes are webbed together, and the fingers are fastened together into a flat blade with which the turtle rows

Drawn by B. Phillipson

Rowing. The turtle uses its arms this way.



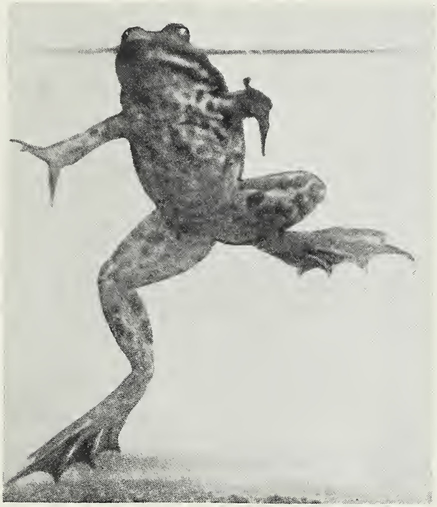
Turtles swimming under water.

From Ditmar's *Reptiles of the World* (by permission of The Macmillan Company, publishers) himself along. Sometimes the fore-limbs, which are the oars, are used together: sometimes they are used turn about. When they are used turn about, it is rather like the overhead trudgeon stroke of a man swimming. The hand is raised above the turtle's head: then it is brought forward, downward and backward, *broadside on*, with great strength. As it comes down, it pushes back a handful of water, and the turtle's body shoots forward. Then, in the up-stroke, the turtle turns his oar-hand very neatly, so that this time the blade moves *edge on* through the water and offers as little resistance as possible. For this up-stroke is not meant to drive the animal along, but simply to bring the oar back into position for the next down-stroke.

The turtle's hind-feet help with the steering. But a lot of the steering is done by the front-limbs. You know how a man can steer his boat with his oars as well as with the rudder. If the man wants to turn his boat to the right, he stops pulling with his right oar and pulls hard with the left one. The turtle does the same. When he wants to turn to the right, he works furiously with his left arm and stops swinging the right arm until he has spun round.

Talking of turtles makes me think of some much commoner animals that swim by means of their webbed *hind*-feet. Ducks, for instance; and frogs. The duck's three front toes are held together by a web of skin. The duck paddles along with its two feet, using them alternately; folds its toes together as it brings the foot forward, and then spreads out its toes and the webs between and pushes back strongly so that the foot scoops away the water and the body shoots forward. Again, you see, it is like using an oar-blade for rowing. If we human beings had webs between our fingers, it would save a lot of trouble in learning to swim. Because, as you know, it is not easy at first to remember that you must try to make an oar-blade with your hand. If you let your fingers separate from one another, so that your hand strikes the water like a fork instead of like a spoon, you don't get a good scoop, and the stroke won't be nearly so effective.

Lastly, just a word about the frog. When the frog is young, we call him a tadpole; and the tadpole spends all his time in the water swimming rather like a fish by side-to-side wiggling movements of his long, finny tail. (*See* the picture on p. 67.) After the tadpole grows his legs, he turns into a frog and loses his tail. Some part of his time the frog now spends on land, and in last chapter I said a little about the way he moves over the ground. But when he gets into the water the frog now swims with his long hind-legs, which have webs between the toes. The legs are used then, not turn and turn about like a duck's, but just as a man uses his legs in swimming: first they are gathered up below the body, and then struck out straight back, both together. In that strong back-stroke, the webs of the frog's foot are all spread out, to give a good oar-blade for shoving against the water.



Photo, Ray Palmer

Frog swimming under water and coming to the surface for a breath of air.

CHAPTER VII

HOW ANIMALS MOVE IN AIR

WHY FLYING IS DIFFICULT – ANIMAL PARACHUTISTS – FLYING IS WELL WORTH THE TROUBLE – THE BIRD SOLVES THE PROBLEM – STREAM-LINING AGAIN – WINGS ARE ARMS – FEATHERS – ROWING IN THE AIR – THE BAT'S PLAN – THERE ONCE WERE FLYING DRAGONS – THE INSECT'S WING

IN last chapter we saw that moving in water is in some ways more difficult than moving on land, because water is a thicker stuff to push your way through than air is. So when we come now to flying, it looks at first as though this should be the easiest way of moving about. Easier, I mean, than levering yourself along over the ground, and easier than shoving your way through water. And so you may wonder why so few kinds of animals have made use of the air for travel, for there seems so much more room for them up there.

But we also saw that water has this advantage – it buoys the animal up. And on the ground the animal at least has something solid under its feet. Up in the air there is no help of that kind. Keeping afloat in the air is no easy matter, even if the animal has a very light body.

A number of creatures have solved part of the problem, and though they can't actually fly, they are very good at gliding. Some squirrels in tropical countries have parachutes of skin stretching along the sides of their bodies from front-paw to hind-paw, and from the hind-paw to the tail. When they are on a high branch, these squirrels jump into the air, spread out their limbs, and glide down safely to a lower branch by the help of the skin parachute.

This power of gliding, though very useful, is not to be confused with real flying. The real fliers strike the air with wings; they row in the air with wings for oars, a little bit in the same way that the turtle swims when he is swinging his front limbs both together. There are only four kinds of animals that have completely solved the flying problem. You can guess three of them easily enough – birds, bats and insects. These three kinds live on this earth to-day, and we all know them. Once upon a time, though, millions of years ago, there really were flying dragons as well: but for some reason the flying dragons have all died out.

Birds, bats and insects are very different from one another. But they are all alike in three ways – they are small animals of their kinds, they are very light animals, and they move in the air by striking it with wings.

Flying animals have a wonderful time of it, I think. If an animal can once get over the great difficulties of rising off the ground and moving through the air, what splendid freedom that gives! Think what it has meant for human beings since they have invented aeroplanes. When I was a child there were no aeroplanes, and the fastest you could travel was in a train that went only about forty miles an hour. Nowadays people travel thousands of miles in the air at three times that speed, or more; and they can move in any direction, since they are not limited by roads and railway-tracks and traffic blocks and all other hindrances of ground-travel. All the flying animals have this marvellous freedom and speed: even a smallish bird like a pigeon can fly as fast as most express trains. No wonder the animals were anxious to take to the air and get away from the crowded land. But the difficulties, as I have said, were very great.

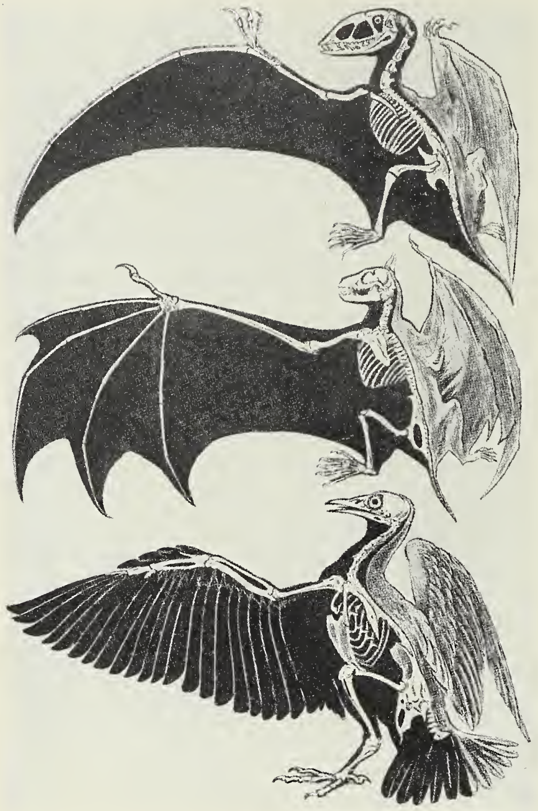
Let us consider the bird first and see how the problem has been solved there. Almost all birds are smallish vertebrates, and some are no larger than big insects. There are eagles, of course; but the bigness of an eagle consists a good deal in the immense stretch of the wings: actually the body itself is not very large. You might say, 'But what about ostriches?' Yes, but then remember that ostriches cannot fly. That is the point. They are too big and too heavy to raise their bodies off the ground with wings. Or, to put it the other way round, they are able to be the size they are – so much bigger than other birds and so much heavier – because they have given up flying and have gone back to running on the ground.

Then, the body of the flying bird is extraordinarily light, even for its small size. It has air-bags inside it; and even its bones may be filled with air, instead of having red marrow in them as our bones do.

And of course you can see that the bird's shape is the best possible for fast travelling. You remember that the best shape for fast travelling through water is the stream-lined shape of the fish. Well, that is true also of travelling through the air. (*See* p. 29.) Think of the fast aeroplane and of the dirigible airship. The bird's body is very perfectly stream-lined. A smooth outline, the body plumpest in the middle and pointed fore and aft, with a deep, ridged breast-bone making a sort of keel to the boat. As little as possible sticks out from the surface of this shape. The feet are tucked up out of the way as the bird flies. And the feathers that cover the body point backwards just as the fish's scales do, so that they do not fluff up when the air strikes them.

What is not obvious, however, until you examine the inside of a dead bird, is that the 'ballast' is so suitably distributed. Well down in the hold of the bird ship lie all the heavier organs – the liver and intestines and the rest; while the air-filled lungs and air-sacs make the front and upper parts of the ship light. The whole affair is light and springy, but very strong, and beautifully balanced.

And now for the wings. The bird is really a four-legged, backboned animal that has learnt to walk on its hind-legs and has turned its front limbs into flying apparatus. The wings of a bird are just its arms, plus the feathers that grow on these. You can easily convince yourself of what I say if you look at the picture of three winged animals with their skeletons showing through. The bird is the one at the bottom of the picture. And you can see that in its wing are the same arm-bones that are in ourselves and in the dog. There is one long bone next the body; then, below the elbow, two bones;



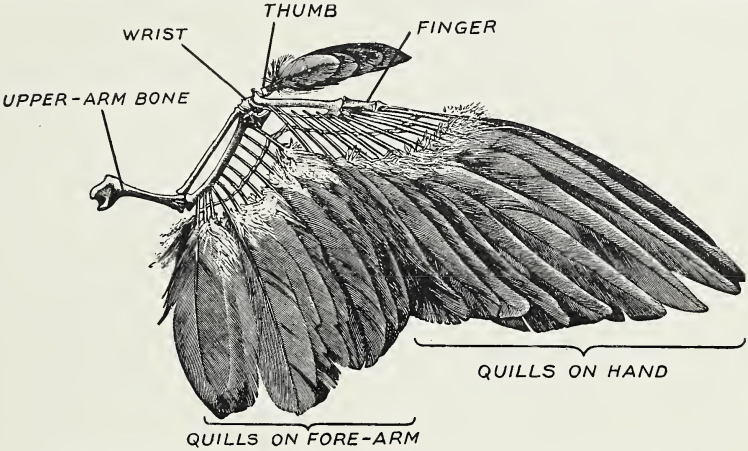
Drawn by L. R. Brightwell

Arms as wings. Above, an extinct flying dragon. In the middle, a bat. Below, a bird.

From Wells, Huxley and Wells' *Science of Life* (Cassell & Co., Ltd.)

then comes the wrist; and lastly the hand. But notice what a queer, stiff-looking, narrow hand the bird has. There are almost no fingers: you will find just a tiny scrap of bone for the thumb, and very small pieces for two fingers: all the rest has gone. A hand like that is no earthly use for climbing with or for walking on. In fact, the bird's hand has become just part of the stiff support for the feathers of the wing.

In the picture, the bird has stretched out its left arm. You might imitate that. Stretch out your left arm, too – but not quite straight: keep it a little bent down at the elbow and a little bit up at the wrist. That is the position of the bird's arm when it is extended for flight. But now, fold your arm up, as you see a bird doing with its wing when it settles on a branch. To do that you must bring your wrist as near as you can to your shoulder, and then try to touch the outside edge of your forearm with your little finger. You'll find you can't actually touch it; but that doesn't matter. What you *have* done is to bring your hand and arm into the folded-wing position of the bird, like a sort of letter Z.



Wing of a dove. The flesh and the wing-coverts have been removed.

From Thomson's *Outlines of Zoology* (Oxford University Press)

The bird's arm, however, is just the framework of the wing, to support the feathers. This is shown in the picture called 'Wing of a dove.' Large, strong quills grow out from the lower side of the forearm, and another set of these grows out from the hand part: there is a little special tuft of feathers fixed to the bird's scrap of a thumb. These big quills of the arm and hand are held to one another by a sort of string near their roots. The whole arm and the spaces between the roots of the wing-quills are covered with a carpet of much smaller feathers,[1] like those in the thumb-tuft, and this prevents the air from whistling through the cracks; because you can see that if the air blew through the wing, it would spoil the force of the oar-blade when the wing strikes the air. It gives the same effect as the webbing between the frog's toes, or the duck's. But though I speak of the bird's wing as an oar-blade, I want you to realise that when it is stretched out for flying, with all its quill-feathers spread, the wing is not just a flat thing like the paddle of a canoe. It is scooped out underneath, especially towards the armpit.

A feather sprouts out of the skin, much as hairs do; but it is a far more complicated thing than a hair. Look at the picture of wing and tail feathers. There is a main stalk or shaft, which is hollow near the skin and solid further out: and from the sides of the solid part grows out the web or 'vane' of the feather. This web is not a simple flap. On each side of the feather stalk it is made up of hundreds and hundreds of tiny branches called 'barbs'; and the barbs are held together by still tinier hooks. Each barb holds on to its neighbour by its hooks, so that the whole thing is clipped together into a flexible sheet. You can't see the hooks unless you look through a microscope at a bit of feather; but you can guess they are there when you try to pull the barbs of the vane separate from one another. It takes quite a tug to separate the barbs, so firmly do the little hooks grip.

The wing is not the only part of the bird that has big quill-feathers. The tail looks quite long, but it isn't really – as you can see if you examine a plucked fowl. Indeed, the bird's tail is really very short and stumpy: but it has a row of quill-feathers rooted in it, and these are what give the apparent length. The bird can spread out these quills like a fan, or fold them over one another into a flat bunch.

Now that I have described some parts of the flying machine, we can go on to see how they are used. Take a good look at the pictures on p. 43.

The wings are unfolded, and then raised above the back: (Fig. A) and then they are brought down together, with a strong push,—*downwards* and *backwards*. (Figs. B and C.) As this happens, the air is pressed downwards and backwards by the wing-blade. The scooped-out shape of the underside of the wing helps very much to get a good grip on the air that is being shoved away. And of course, as the air is displaced by the wings, the body of the bird is moved *upwards* and *forwards*. Great strength is needed for this down-stroke, for the bird's light little body is heavier than air. When the wing has reached the bottom of the stroke, it is quickly raised upwards and forwards, to be ready for the next down-stroke: and, in this up-stroke, the air tends to glide off the arched back of the wing.

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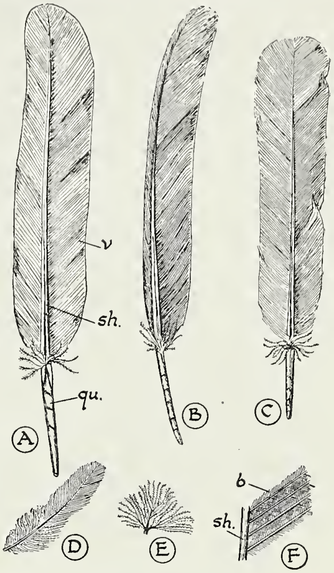
[1] These have been removed in the picture.

When I put it like that, I am really simplifying things too much. It is not just a flapping up and down. There is also a kind of a twisting, and the tip of the wing describes a sort of figure 8 in the air – a figure 8, of which the lower loop is much smaller than the upper loop.

A great deal of the steering is done by the wings. The bird can steer by making strokes of different strengths on the two sides of its body, with the tip, the hand-part, of the wings. For instance, if the bird wanted to turn to the left – to port, as sailors say – it would strike more strongly with the tip of its right, its starboard, wing. In birds that can wheel very rapidly, as the swallow does when chasing insects, you'll notice that the hand-part of the wing is very long in proportion.

Probably the tail helps in steering, as well as in balancing; and it can also be used as a brake. You must have noticed how a pigeon spreads out its tail and turns the feathers down when trying to land on the ground.



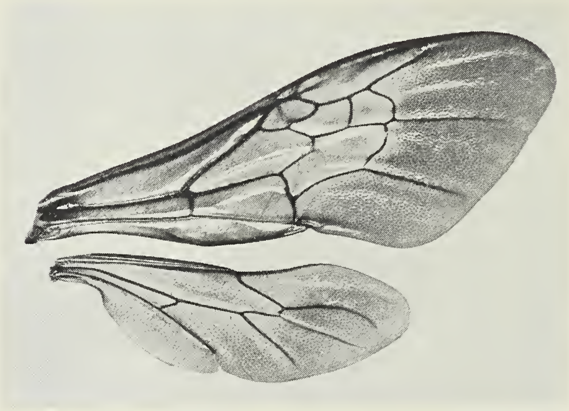
Pigeon's feathers. A and B, wing feathers; C, tail feather; D, covering feather from the body; E, down feather; F, small part of a feather drawn large to show the barbs; b, barb; qu, quill; sh, shaft; v, vane.

From Phillips and Cox's *A First Book of Biology* (University of London Press, Ltd.)

Taking off from the ground, or from a branch, and then the first few strokes – that is the hardest work for the bird. After some speed has been got up, much less effort is needed: and when the bird has really got going, a lot of gliding comes in. Coming along with the wind behind it, a bird uses its wings partly like sails. Sometimes when it seems a perfectly still day to us on the ground, we see seagulls moving along quite high up, with only an occasional beat of the wings to keep them from sinking. No doubt there are air-currents up there, helping the bird to sail so easily in what seems to us windless weather.

The bat is another successful flier: but the bat has followed a different plan from the bird. One of the bat's difficulties is that he hasn't any feathers. The bat is a furry animal, and you can't turn hairs into feathers. If you can't have feathers, you have to make the web of your wing in some other way. So the bat has made it out of a fold of skin. But notice that this is not a mere parachute; it really is a wing, striking the air in flight. In the picture of the bat on p. 38 you see that again the arms are used as the framework; but instead of the hand being small and stiff, as in the bird, the bat has kept all his digits, and the fingers have grown immensely long and slender to act as a support for the skin-fold – something in the way that the steel ribs of an umbrella hold out the cloth.

The only other backboned animal that ever really flew was the winged dragon. You see him just above the bat in that same picture on p. 38. The flying dragon had wings of skin, like a bat. But notice that the support here is different. The little finger grew enormously long, and the whole of the front edge of the wing was held up by that alone.

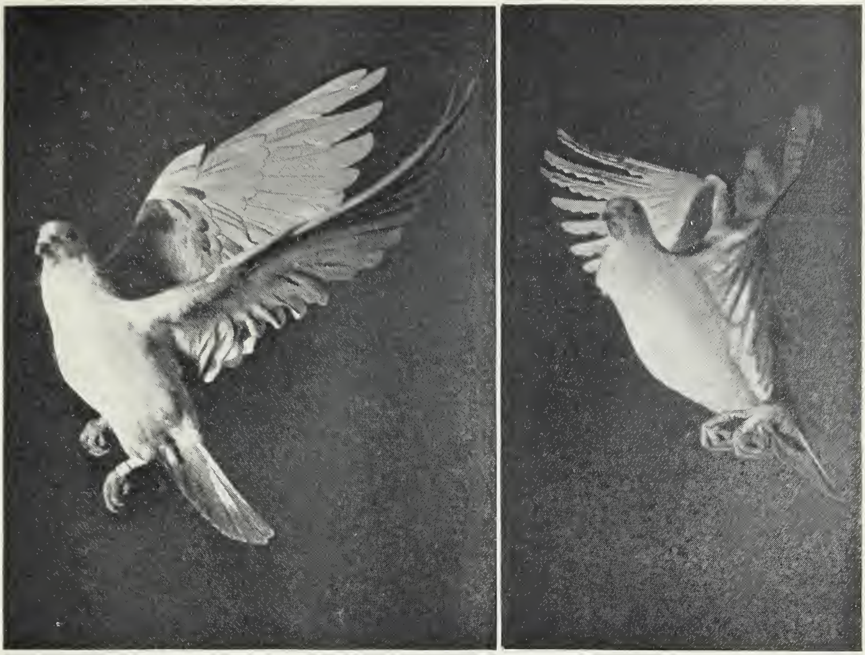


Photo, H. Bastin

Wings from one side of a bumble bee.

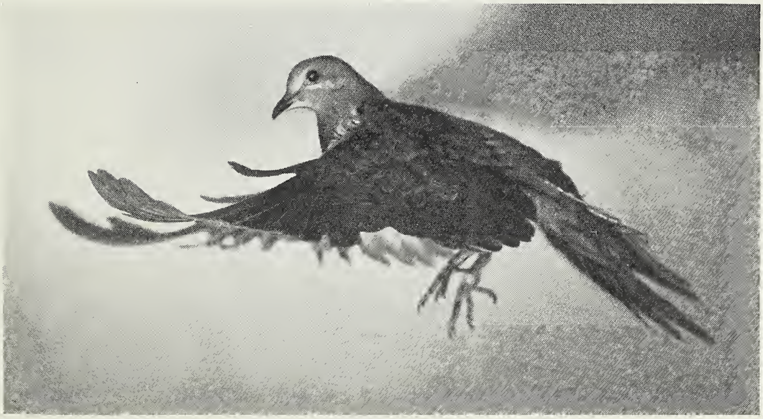
To discuss the wings of insects would take a whole chapter for itself. Here I shall just point out what are the chief differences between the wings of an insect and the wings we have been considering. An insect's wings are *not* made from its limbs. They grow out from the sides of the insect's body in the middle part where the legs are, but nearer the back. The wing here is a thin, horny plate, usually as transparent as gauze, and stiffened by a delicate branching framework. House-flies and gnats have only one pair of wings: butterflies and dragonflies and bees and beetles have two pairs.

BIRD'S FLIGHT



A. Wings raised above the back.

B. Beginning the down-stroke.



C. The down-stroke nearly completed.

A and B, pigeon; C, dove.

Photographs by Harold E. Edgerton and Kenneth J. Germeshausen

CHAPTER VIII

A BIRD'S MUSCLES

WHY THE BIRD'S ARM IS SO SKINNY – WHY THE BIRD'S BREAST IS SO PLUMP – MAJOR AND MINOR – THE MERRYTHOUGHT – THE SHOULDER-PULLEY – TWO-LEGGED TOE-WALKING – WHY THE SLEEPING BIRD DOES NOT FALL OFF ITS PERCH

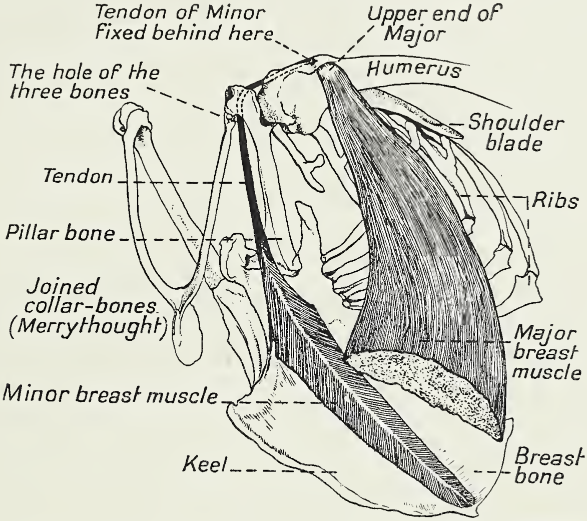
THIS seems a good place to say something more about muscles, because in the bird some of the muscles are tremendously developed and the way they are used is interesting.

When you look at the wing of a dead bird that has been plucked, you can see the reddish muscles of the arm showing through the skin. A thing you notice at once is that the arm is thin and skinny. The wing of a fowl hasn't much meat on it. And this at first seems rather odd, because, as I was saying in last chapter, great strength is needed to lift the bird's body from the ground and to keep it moving through the air in flight. Since the bird flies with its wings, you would expect its arm-muscles to be powerful, and therefore thick and bulgy. Actually, however, they are small, rather feeble things.

What is the explanation of this ? The answer is that the bird does not use its arm-muscles for the actual flying movements. The bird uses its arm-muscles just for stretching the wing out and for folding it up again. These are simple, easy movements, and large, powerful muscles are not needed to perform them.

If the muscles for the actual flying movements are not in the arm, where else can they be ? If you guess that right off, I shall be surprised. They are in the bird's breast. The breast of a bird is much the fleshiest part of it, as you know; there is more meat there than anywhere else when it comes to carving a cooked fowl or a turkey. And all this mass of flesh on the breast of the bird is made up of the great flight muscles which move the wings down and pull them up again. Muscles for such hard work have to be powerful; and powerful muscles are large, and they are heavy. Since there has to be this weight of muscle on board the bird boat, it is best that it should be kept well down below; that helps to give the right balance and it improves the stream-lined shape.

But before I can explain to you how these breast-muscles work, I must say some things about the skeleton they are fixed to. Look again at the bird's skeleton on p. 38; and then at the picture on this page. What you see here is a drawing of the left-hand side of the bird's breast: but everything has been removed except the bones and the chief flight muscles. The white parts are the bones: the stripy parts are the muscles: the black line is tendon fastening muscle to bone. The biggest bone in the picture is the breast-bone. Your breast-bone is a flat, narrow thing, and not very long. The bird's breast-bone is very unlike yours. It is broad and shield-shaped, and it covers much more of the front of the body than yours does. And from the flat part there sticks out a high ridge of bone, called the 'keel.' From the top of the breast-bone, on each side, there is a bone going forward to the armpit: I am going to call it the pillar-bone because it is shaped rather like a short, thick pillar. (We do not have this bone in our own shoulder-girdle.) At the top of the pillar-bone lies the shoulder-blade: only a tiny piece of it shows in the picture, because it passes over the bird's back. The bird has collar-bones, too; but in the



Drawn by B. Phillipson

A bird's breast dissected to show the chief flight muscles in relation to the skeleton (left side).

bird they are joined together in front to make a piece shaped rather like a pair of tongs. These joined collar-bones are what we call the 'merry-thought' or 'wish-bone' of the bird. The picture also shows a bit of the top of the upper-arm bone, the humerus.

Now for the breast-muscles of the left side. The stronger, larger muscle is the one you cut into first when you carve a bird's breast at table. In the picture, it has been carved right away from the bone and you look partly at the cut end. We call this the 'major' muscle. Before it was carved off, it was fixed partly to the shield part of the breast-bone, but chiefly to the keel all the way along. From there it passes forwards towards the shoulder, and near its end it turns into a glistening, blue-white tendon, which is fixed to the *front* of the upper-arm bone.

Imagine now what will happen when the major muscle contracts. The breast-bone is held pretty steady by the ribs and the pillar-bones. The arm-bone, however, can move freely. So when the major breast-muscle shortens and thickens, the arm-bone is pulled down towards the breast. The result of this, of course, is that the wing is lowered. As we saw in the last chapter, that downward movement of the arm gives the strong, flying stroke. The outer breast-muscle has to do the really hard work in flying, and that is why it is much the biggest and heaviest muscle in the bird's body.

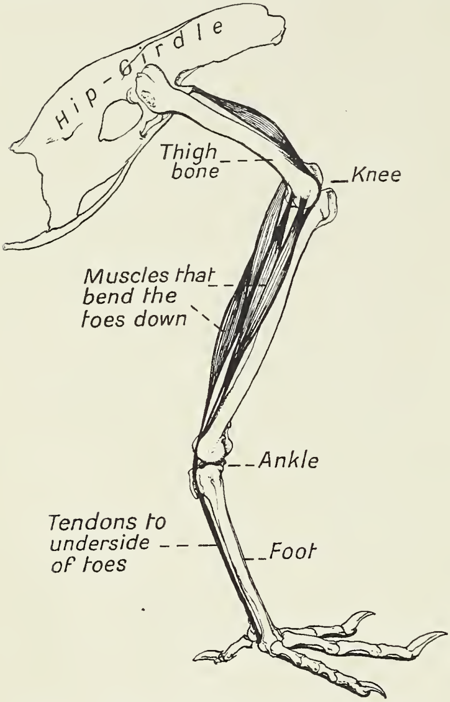
After the wing has been lowered, the major muscle relaxes. Then the wing is lifted up into position for the next down-stroke. Here I would remind you that muscles work in pairs: one muscle of a pair will bend a joint, and the opposite muscle will straighten the joint. So if the major muscle of the bird's breast lowers the wing, you would expect there to be an opposite muscle to do the opposite work – a muscle, that is, to raise the wing. And so there is. But it is in a queer place. Since the lowering is in the breast, it would be natural to look for the lifting muscle on the bird's back. You won't find it there, though. Surprising though it seems at first, the wing-lifting muscle also lies in the breast, deeper in than the lowering muscle, so you can't see it until you have carved that one away. The lifting of the wing is much easier than the down-stroke, so this second muscle is a good deal smaller, and we call it the 'minor' muscle of the breast. In the picture, since the major muscle has already been carved away from its attachment, the minor one shows clearly. It too is fixed to the breast-bone, and it passes up towards the shoulder, getting narrower as it goes: presently it also turns into a glistening tendon. This tendon, you see in the picture, is a much longer one than that from the major muscle, for it has farther to go before it is fixed to a bone.

Next you will notice the very peculiar way this tendon is threaded between the bones at the shoulder. Where the pillar-bone, the collar-bone and the shoulder-blade meet one another, there is a little gap; and through this gap the tendon of the small breast-muscle is passed, like a thread through the eye of a needle. That is shown by the dotted lines in the picture. Beyond the hole, the tendon is at last fixed to the *back* of the upper-arm bone, a short way below the shoulder. I want you now to imagine what will happen when the minor muscle contracts. The breast-bone is held steady and cannot be pulled up. So, as the muscle shortens and thickens, it will tug on its tendon in front: and the tendon, which runs through the hole at the shoulder, will work like a rope moving over a pulley. It will drag on the upper-arm bone and will raise that. This is what is happening inside when the bird lifts its wing in flying.

Because the bird, although a four-limbed creature, reserves its arms for flight, it has only two limbs to walk on. The bird, like the man, walks on its two hind-limbs: and, as you know, that makes balancing difficult. The bird has a special way of its own of keeping a balance on two legs. Even when it is standing still, the bird's legs are not straight pillars, as ours are when we stand erect. The bird's legs are always kept bent – very much bent at the knee and less bent at the ankle. You may remember that, like the dog and the cat, the bird is a toe-walker, and so keeps its ankle high off the ground. The toes of the bird are long in proportion and are spread out from one another flat on the ground, to give a broad foundation for the animal to stand on. Looking at a live bird, it is difficult to realise at first that the legs are bent into a zigzag, because the feathers cover so much that very little of the leg shows. What you see of the leg in most birds when they are standing or walking, is really just the sloping foot part and the toes: all the rest – the part from the ankle to the knee, the knee itself, and the thigh – is hidden under the feathers. But if the feathers are taken away, you get a very different view.

The legs have to be strong enough and springy enough to hold the body up from the ground and to walk with: but they must not add much to the weight, because of flying. So the bones of the leg are usually very light, and again there is great economy with the muscles. You must often have noticed that the upper parts of a fowl's legs are the only parts with anything worth eating on them: the thigh is the most muscular; the calf, or 'drumstick' part, is leaner; and the foot is so stringy that it is generally cut off as useless, before the bird is cooked.

If you take the skin off a dead fowl's foot, you will see then how little flesh there is. At the back of the foot you will find a bunch of white cords, tendons. If you pull this, you will find that the toes all curl in. The bunch of tendons down the back of the foot divides to give the toes one tendon each, and these run along the under side of each toe. All you have got is the foot; but, if you had the whole leg, you could follow the bunch of tendons from the foot up into the leg. You would find that it passes round the back of the heel, and in the small calf of the rather skinny leg the tendons join on to muscles that are fixed to the leg-bones higher up. So, when a bird wants to curl its toes in, all it has to do is to contract these muscles high up in the leg: the long tendons do the rest.



Bird's right leg showing bones and those of the muscles that bend the toes down. Tendons shown as thick black lines.

If you have ever kept a canary as a pet, you must have noticed its position when it is asleep. Birds do not usually lie down when they go to sleep. Most birds get off the ground and go up to some safe place like the branch of a tree, just as your canary goes up to its perch. And they remain on the branch, sound asleep, all through the night. You would think it must be a very tiring thing to do, to hold fast by your toes to a perch all night: but the bird doesn't seem to find it a bit tiring. It keeps its balance for hours and hours, sometimes tucking one foot into its feathers and holding on by the other only; and it wakes up quite spry when morning comes. As a matter of fact, the bird is not making any special effort to keep from falling off. It is not contracting its leg muscles in order to hold on with its toes: that *would* be terribly tiring. What is happening is this: –

I have explained that the bird's leg is always rather bent at the knee and at the ankle; even when it is standing or walking, the bird is always crouching a little inside its feather coat. Now when the bird settles down for the night, it literally does *settle down*. As it falls asleep, its whole body relaxes; and its weight, such as that is, sinks lower and lower until the bird is practically sitting on its heels. The leg, you see, gets more and more bent at knee and ankle. As this happens, the tendons I was telling you about are pulled tighter and tighter round the pulleys of the knee- and ankle-joints, and they curl in the toes tighter and tighter round the branch. So the sounder the bird is asleep, and the more its legs get bent under its sleeping weight, the more securely do its curled-in toes grip the perch. As long as it is asleep, the bird is sort of locked to the perch by its toes, and is most unlikely to fall off. The creature has to wake up and raise its body by straightening its legs a bit before it can undo its toes and fly away.

CHAPTER IX

CREEPERS AND CRAWLERS

HOW THE FLY CAN WALK UPSIDE-DOWN – WATCH A LIVING EARTHWORM CRAWL – BRISTLES GIVE A HOLD – YOU CAN SWALLOW FOOD EVEN WHEN YOU STAND ON YOUR HEAD – THE SNAIL'S FOOT – A MOVING STAIRCASE – A SNAKE IS NOT A WORM – SNAKES ONCE HAD LEGS

YOU may have noticed that in the chapter on getting over the ground, I mentioned only the backboned animals with four limbs, such as dogs and horses and frogs. It wasn't that I had forgotten about the other animals, the smaller creatures, like insects and worms and snails, which also move on land. I intentionally omitted these, because to put them in there would have made the chapter too long; they need a chapter to themselves.

We have seen that all the backboned animals are made on one pattern really. The animals without a backbone, the invertebrates, are made on several patterns, different from one another and all very different from the backboned pattern. It isn't just that there is no backbone: there isn't any inside skeleton of bone at all. And, as I explained in Chapter IV, if the invertebrate has a skeleton, that lies outside the soft parts, not inside them as in us and the rabbit.

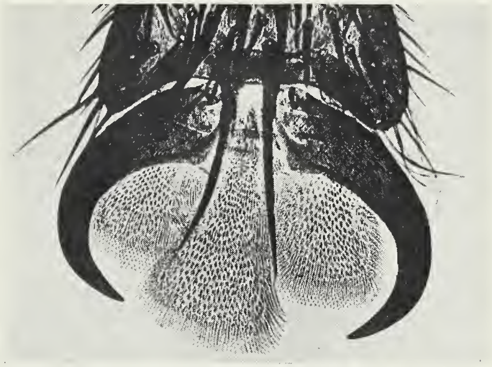
Since it has an outside skeleton of hard, horny stuff, an insect can have stiff, jointed legs; and this means that when the insect is not flying, it can walk or run, with its body carried well off the ground.

It is true, we say that a fly 'crawls' on the ceiling. But the fly's crawling is really a quick 'walk' or 'run,' since it gets along by moving its limbs. The fly has three pairs of limbs, instead of only two pairs as a vertebrate has; and the parts of the limbs do not really correspond to the parts of our arms and legs. The fly's foot ends in two little claws, and between these are set sticky cushions: it is the sticky cushions on its six feet that enable the fly to run easily up a smooth sheet of glass, or to walk on the ceiling upside-down.

I prefer to keep the word 'crawl' for the way those animals get over the ground that have no limbs at all – earthworms, for instance, and slugs.

In these creatures there is no skeleton, either inside or outside; and so there cannot be any true limbs, for a soft limb would just go squash if the animal tried to stand on it or walk with it.

I shall take the earthworm as my first example of a real crawler. You will find it much easier to follow my description of how it moves, if you have a live earthworm to watch; but even if you haven't a worm to look at, there is no need for me to describe its shape, for 'worm' is almost a name for a shape. When you read that word, you can see the animal at once in your mind's eye – a soft, rhubarb-coloured, pencil-shaped thing, six to eight inches long. The soil of every garden and field swarms with worms: they really are 'as common as dirt.' Most of the time, they stay down below: even in damp, warm weather you seldom see them at the surface, for during the day they live in burrows they make in the soil. If they come willingly to the surface, it is in the darkness of the night when the birds are asleep; and even then they generally keep their tails in the openings to the burrows so that they can slide back quickly into safety at the least alarm.



Photo, E. A. Botting

The fly's foot, showing the sticky cushions.

The shape of the worm suits this underground life very well. I said that the body was shaped like a pencil. But that is only partly true. Towards the front end the pencil gets thicker, just before it tapers off to the point at the head: immediately below the point lies the little mouth. (*See* picture on p. 185.) Then, at the tail end, the pencil is slightly flattened from above downwards. Now, a body like that – pointed in front, then getting thicker, then rather narrow again and of the same narrowness nearly all the rest of the way – a body like that is excellent for pushing through soft earth, as the worm does when it is burrowing. But the worm doesn't merely push the earth aside, as you do when you shove a pointed stick, like a pencil, into the ground. The worm actually swallows the earth as it goes along: it *eats* its way through the soil.

You have noticed, of course, that the earthworm's body seems to be

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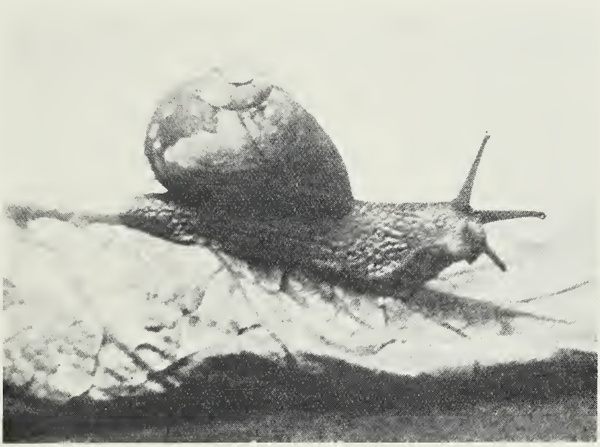
made up of rings. There are about one hundred and fifty of these rings on the outside of the worm. If you pick the creature up, very gently, and draw your finger-tip along its paler, under side, *from head to tail*, you notice nothing special except that the skin is moist. But if you stroke the under side of the body the other way, *from tail to head*, you get a different feeling; the skin seems prickly. What you feel then are the sharp, projecting points of small, curved, horny bristles which lie embedded in the worm's skin. There are four pairs of these bristles to almost every ring of the body. The worm can move its bristles to and fro, but the tips of them usually point backwards; and when the worm glides over the ground or squeezes its way down its burrow, they stick into the soil and so help to crutch the body along. If a blackbird gets hold of the worm, the bristles are stuck into the sides of the burrow and hold on like grim death. If you put your worm on a bit of rough paper and listen closely while it crawls, you may hear the faint scratching sound of the bristles. And now you see why, if you put the worm on a very smooth surface, like glass, it cannot move forward easily – there's nothing there for the bristles to get a grip on.

Watch the shape of the worm as it crawls. It raises its head from the ground and stretches it forward, and, as it does so, the head gets long and thin. Then it puts down the stretched-out head further forward than it was at first; then this part gets shorter and fatter again and the bristles are dug in to hold it steady. The same process of lengthening and thinning, and then shortening and thickening, gradually extends backwards to the tail. Then the head is put forward again. Little by little, in this way, the whole of the worm gets shunted along into a new place.

What makes the worm's body get alternately thin and thick is the action of two coats of muscle. Just under the thin, damp skin of the worm is a layer of muscle threads arranged so that they run *round* the body. Now when the worm's head is getting longer and thinner, what is happening is that these circular muscles are contracting; and, as they shorten and thicken, they squeeze in the worm's shape. Then the muscle threads of this outer coat relax; and the worm next contracts its inner coat of muscle. The threads of the inner coat run longways in the body, not round it like those of the outer coat; and when *they* shorten and thicken, the effect will be to make the body thicker and shorter. Then these muscle threads relax and the circular set begins to tighten. So it goes on all the time the worm is crawling – lengthening, shortening, lengthening, shortening; the circular coat muscles and then the under-vest muscles contracting turn and turn about.

You noticed that the whole worm does not lengthen and shorten all together at one time. If that happened, the worm would stay pretty much in one place ! Bit by bit, starting from the head end, the contraction, and the change of shape it produces, goes all along the body in a wave.

Very much the same sort of thing happens in your own gullet when you swallow a mouthful of food. The gullet is a tube leading down from your mouth to your stomach; and in its walls, just as in the walls of the worm's body, are two layers of muscle threads – the one set running round the tube, and the other set at right angles to these. The two sets contract turn and turn about, beginning at the mouth end of the gullet and finishing off at the stomach end. The idea here is, not to move the gullet along, but to make its walls grip the mouthful of food you have swallowed and squeeze it gradually downwards to the stomach where it will be digested. I don't advise you to try this, but it *is* quite possible to swallow when you are standing on your head, because the contracting gullet walls always press the food in the direction of the stomach whether you are upside-down or the right way up. (*See* picture on p. 87.)



Photo, H. Bastin

The snail puts out its horns.

But let us come back to our crawling animals. . . . The snail, like the earthworm, has no skeleton – unless you choose to call its shell an outside skeleton. But the snail's shell is more of a house than a skeleton. The snail's body has two main parts. There is the part that is always inside the shell – the liver and intestines and delicate organs like that – and then there is the part that is outside the shell when the snail is crawling. This outside part is chiefly made of muscles, and it is called the foot. Above the foot, in front, is the snail's head with the mouth and the horns or feelers.

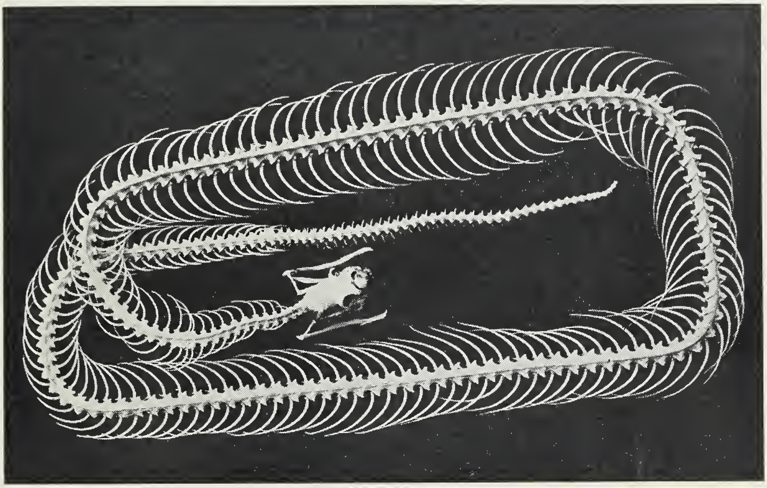
It is the foot of the snail that does the crawling. It has a broad, flattish sole, which is very smooth and slimy. The slime pours out from a hole in the front of the foot and gets in below the sole, where it forms a sticky layer which helps to make the foot stick to a smooth surface. If you put a live snail in a tumbler, you can watch it crawling up the smooth glass, to which it holds on quite easily by the help of the slime; and, as it goes along, it leaves a trail of slime behind, marking its path.

You should look closely through the glass at the pale underside of the snail's sole. As the snail moves along, you can see slightly darker lines appearing across the sole, like shadows. There are about twelve of these lines. You will notice that they don't stay still. Each shadowy band moves forward towards the snail's head and disappears, and a new band comes along from behind to take its place. This gives a sort of rippling effect, and the rippling goes on until the snail stops crawling.

The foot of the snail, as I said, is made of muscle threads under the skin. And what is happening is that the muscle threads are shortening and thickening at each of these shadowy lines, and lifting the sole a tiny bit off the glass just along that part. The effect of this is to drag forward the paler strip of sole immediately behind. After it has done its work, each shadowy band relaxes and gets pale; and then it is the turn of the pale strip just behind to shorten and get darker and do the dragging forward. As this is happening at about a dozen places across the sole at any one moment, you get a gradual pushing forward of the whole foot along the slimy track that the paler strips are touching. I have seen the snail's way of crawling compared to the moving staircase at certain underground railway stations. That is only a rough comparison, but perhaps it helps you to picture what is happening.

My last example shall be a snake. A snake is shaped something like a worm, and they both crawl: but that is practically all the likeness there is.

A snake is not made on the worm pattern inside. It is really a backboned animal with an inside skeleton of bone. The backbone here is tremendously long; many of the boa-constrictors are over twenty feet in length. And to nearly all the vertebræ of that twenty-foot backbone there is a pair of ribs. If you feel where your own ribs are, you find they are only round the chest part of your body; you haven't any ribs round your abdomen. But the snake has ribs almost the whole length of its long, long body. Each of the snake's ribs ends against one of the broad horny scales that lie on the skin of its under side. And the swift, zigzag crawling of the snake is done by the animal rowing with its ribs on the ground. To be more exact, the snake uses its ribs like punt-poles, and it digs into the ground with the edges of its scales to get a grip as it slithers along.

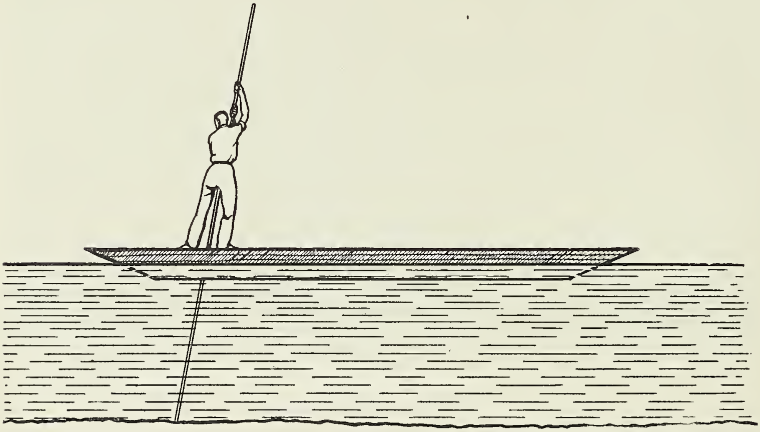


Photo, British Museum (Natural History)

Viper's skeleton.

Just looking at a snake, it is difficult to believe that it is a relation of four-legged animals like lizards and crocodiles. But we have already had examples of animals that have lost the use of certain limbs and have taken to a different kind of moving. The whale, you remember, has lost its hind-limbs. It seems that the snake has lost its fore-limbs as well. For an animal that goes down holes or lurks under stones and brushwood as a snake does, limbs would be a positive inconvenience. So it doesn't have legs any more, and it uses its ribs and scales instead, and has become a crawler. One of the things that makes one suspect the snake of being related to four-legged animals is that, in some of the pythons, there is still a trace to be found of the skeleton of the hind-limbs.

There are, then, at least three different ways of crawling without limbs – the worm's way, the snail's way and the snake's way. And an important thing to notice is that animals leading the same sort of life may be very much the same shape and yet be made on different patterns inside. We saw something of that already, when we compared the fish and the whale. Now here it is again, with the earthworm and the snake. The kind of life an animal leads may determine its general shape and its way of moving; but the true pattern of the animal is still there, and shows through, so to speak, if you know what to look for and where to look for it.



Drawn by B. Phillipson

Punting. The snake uses its ribs and scales this way.

CHAPTER X

THE BREATH OF LIFE

LIVING THINGS ARE BURNING – SLOW COMBUSTION – WHY BURNING IS NECESSARY – WASTE FROM THE BURNING – NO BURNING WITHOUT OXYGEN – BREATHING – LUNGS – A SUCTION-PUMP – BLOOD CARRIES THE GASES – THE BLOOD CIRCULATES – WHY THE HEART BEATS

IF there is no burning, there can be no life. As long as an animal or a plant is alive, it is being burnt. This sounds quite mad.

But why it sounds mad is because, when you think of burning, you think of fast and furious burning, with flames leaping up: and it is perfectly true, of course, that nothing can go on living in a fiery furnace. Burning, however, can be ever so much gentler and ever so much less noticeable than the burning you get when you strike a match and then put the flame to paper or wood and coal.

If a piece of iron is exposed to the air long enough, it gradually turns rusty. Perhaps you do not believe me when I say that this rustiness of the iron is due to burning? It is a very slow burning, true; but it *is* burning, for all that: the piece of iron gets slowly, slowly used up as it rusts, and actually a little heat is given off. The burning, the combustion that goes on in our bodies is much faster than the rusting of iron, but not nearly so fast as the burning of coal in the grate.

Notice that this rusting of the iron would not have happened unless the iron had been where the air could get to it freely. No burning, not even the slowest, can take place if the air is completely shut out. If you want a fire to burn its brightest, you blow it with a bellows, or somehow make a good draught of air go through it. If you put a lighted candle into a vessel and then close this, the candle will burn for a short time and then go out. If you yourself were kept in a room to which no fresh air was admitted, you too would 'go out': you would die. You would die because you could no longer burn.

It is not just the movement of the draught over the smouldering coal that makes the fire leap into flames. If you blew on to the coal a draught of the gas called nitrogen, the fire would not flame up. It is the bringing to the smouldering coal of an ever fresh supply of the gas called *oxygen* that makes the draught useful to the fire. About four-fifths of the air is made of nitrogen: the remaining fifth is made of oxygen. And it is the oxygen that is responsible for all burning – the flaming burning of the fire in the grate, the slow, slow rusting burning of the piece of iron, and the quiet, hidden burning of stuff in the living body. Burning is always the result of letting the gas oxygen get in touch with substances that it can destroy.

Two questions at once come into one's head. What substance is being burnt in the body ? And what advantage is it for the body that this should be burnt ?

In the first chapter of this book, I said that the fuel for the fire of life is food. That is true, but it was putting things rather too simply. I would rather say now that what is burnt in the body is what has been made from the food. For one's body does not straight away burn the meat and potatoes and the pudding and the milk: these things have to be changed before the oxygen that gets into the body can burn them.

What does the burning of this fuel do for the body ? I would say that the burning sets free energy to do work. I hope you will stop me there and say: 'But what is "energy" ?' Because then I have to answer that I really don't know. I don't know what energy is, but I know that it gives the power to do work. I know that electricity is one form of energy, and that light is another, and heat yet another: but that doesn't really help much to explain what energy *is*. And I know that when things are burnt, when they are destroyed by oxygen getting at them, energy is set free. This energy may then be used for doing work.

When coal is burnt in the fire, energy in the form of heat is set free, and it may be used to turn water into steam: steam takes up more room than water, and this expansion of the water into steam is responsible for raising the kettle's lid. When food is burnt in the body, energy is set free. A good deal of this energy is in the form of heat: our bodies are warmed because of the burning that goes on in them. This warmth is very important, for if the living substance, protoplasm, gets really cold, it cannot do anything and it 'dies.' But a good deal of the energy got by the burning of food is used directly for doing the things that are so characteristic of what is alive. The work of moving, for instance, is performed by some of the energy set free by the burning of sugar in the body. If the muscles did not get plenty of this energy from the burning of sugar, they would be unable to contract: then we could not move at all, and our hearts would stop beating. That would be the end of us.

When the substance is burnt, it appears to be destroyed. But really all that happens is that it is changed into simpler substances. Sugar, for instance, is made of three things – carbon, hydrogen and oxygen. When sugar is burnt, two simpler substances are produced: one of these is water, and the other is a gas – carbon dioxide. (For short, carbon dioxide is written CO_2.) This would happen even if you just burnt a lump of sugar in a saucer. When the sugar is burnt in the body, the body has somehow to get rid of the carbon dioxide and this extra water.

You begin to see what breathing is for? Breathing is the bringing of air with its oxygen into the body, and then the getting rid from the body into the air of the waste gas, carbon dioxide, and of some of the water that has been made in the burning process. And you can see why you have to go on breathing all the time if you are not to die.

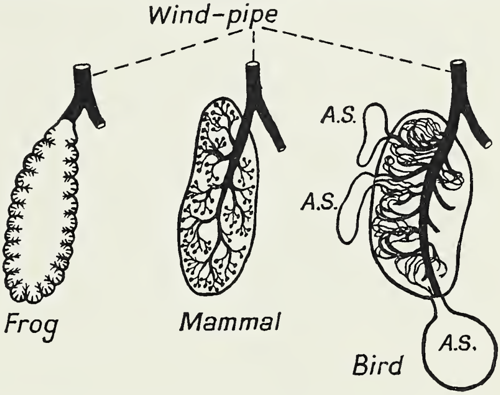


Diagram of inside of right lung in frog, mammal and bird. (The branching of the bronchi in the bird's lung is merely suggested.)

Modified from Dakin's *Elements of General Zoology* (Clarendon Press, Oxford)

The apparatus with which we breathe is in our chests. Inside the chest, one on each side of the heart, are the two lungs. The lung of a human being is a mass of bright pink, spongy stuff, full of branching tubes; and each branch of each tube ends in a little rounded air-bag. The air we draw in through our nostrils goes down the throat by the wind-pipe, the trachea, which lies in the front of the neck. (*See* picture on page 61.) When it gets down to the chest the wind-pipe divides in two, and one half goes to each lung. In each lung the branch from the wind-pipe divides again and again and again, until at last you have the very tiny tubes that end blindly in the air-bags. The lining of the bags is moist, and (very important!) in the lining are a great many small blood-vessels, with blood moving slowly along them. The lungs are extremely elastic: when air comes into them from the wind-pipe, they swell out a great deal, and then all the little air-bags are filled: when the air goes out again, they collapse.

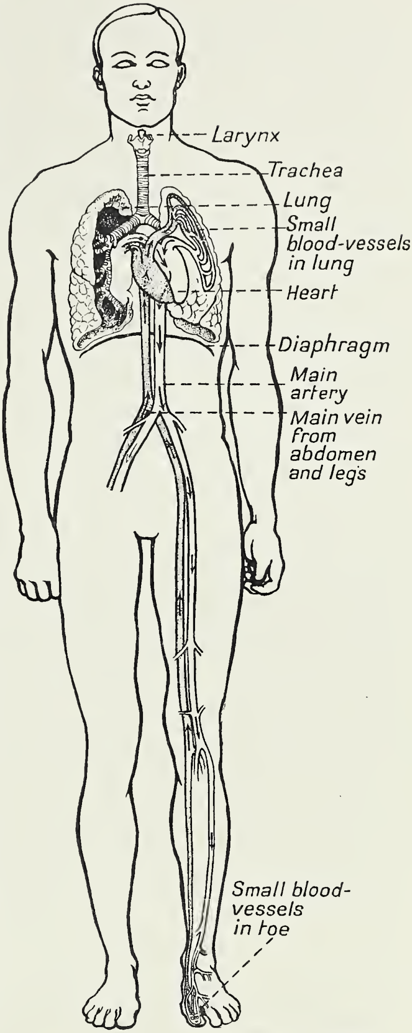
Opening our nostrils is not enough to fill the lungs with air: to get the air down the wind-pipe into the lungs, we have to use the muscular walls of the chest. When I was describing the skeleton, I said the ribs at the sides, with the backbone behind and the breast-bone in front, made between them a sort of cage to enclose and protect the lungs and heart. But I also said that the ribs help with breathing. Between each rib and its neighbour are muscles; and when these muscles contract, the ribs are raised and the space inside the chest is increased.

The size of the space inside the chest is also changed by the movements of what is known as the diaphragm. This is a partition of flesh, dividing your chest from your abdomen inside the body. When its muscles contract, the diaphragm makes a flat floor to the chest: when its muscles relax, it is humped up towards the inside of the chest, and the result of that will be to make the space inside the chest smaller. When you take a breath, then, your ribs and breast-bone rise and your diaphragm sinks down flat: when you let your breath out, your ribs and breast-bone sink and the middle of your diaphragm heaves up. Now, since the lungs are fitted closely to the inside of your chest, and since the space inside the chest is quite air-tight, the lungs move with the chest-wall and floor. When the chest space is large, the lungs are full: when the chest space gets smaller, a lot of the air is driven out of the lungs. The apparatus works like a sort of suction-pump, sucking air down into the lungs: you easily feel, as you breathe, that the intaking of air is the part that requires more effort: breathing out seems to follow almost of itself.

It is all very well to get oxygen into the chest with the air from outside. But that is just the beginning, for it isn't only the lungs that need oxygen. Every part of the body has to be supplied with this precious gas; and every part of the body has to get rid of the waste from the burning that goes on in it. How does the oxygen get from my lung to my big toe, for instance? And how does my big toe get its waste gas back to the lung to be breathed out?

The answer is, by the blood. You remember I said just now it was important to notice that the little air-bags of the lung are lined with tiny blood-vessels? The walls of these blood-vessels are extremely thin, and, as the blood squeezes its way along the vessels, it is very near to the air in the lung. Now the red stuff that colours the blood is extraordinarily greedy for oxygen; and it gets its chance here. It seizes on the oxygen of the air which comes into it from the lung through the thin wall of the blood-vessel; and when the oxygen touches the blood the red colour turns to a brilliant scarlet.

But the blood never stays still. It is always streaming along in the vessels; and in this general stream, the little drop we are watching is soon carried away from the lung. It is taken first to the heart. But it doesn't stop there, for the duty of the heart is to keep the blood constantly moving. At the next beat of the heart, our drop of blood (still holding on to its oxygen) is whirled out again: and this time it goes along a very big vessel, an artery, lying just under the backbone. At the legs, this artery divides into two, and the drop of blood can go either to the right leg or to the left. At the knee, the vessel branches again; and once more the drop of blood has a choice of ways. And now, as it gets down into the foot, the branches of the arteries that it passes get smaller and smaller, until finally our blood-drop finds itself in one of the tiny vessels of the big toe. These are so narrow that the blood in them can flow only very slowly; and here, just as in the lung, the walls are so thin that fluid and gas can pass through. Which is what happens. Here it is


Larynx
Trachea
Lung
Small blood-vessels in lung
Heart
Diaphragm
Main artery
Main vein from abdomen and legs
Small blood-vessels in toe

Drawn by B. Phillipson

Diagram to show (1) position of larynx, trachea, lungs, heart and diaphragm in the human body, and (2) the course taken by a drop of blood from the left lung to the left big toe and back again.

that our scarlet drop of blood from the lungs gives up its oxygen at last and turns a darker colour, and here the muscles of the toe get the oxygen to burn sugar with. In return, they deliver up to the blood carbon dioxide and water.

Back goes the blood to the heart again, along another set of vessels called veins. These, like the tributaries of a river, join together, first in the foot and then in the leg, to give bigger and bigger veins: finally the great veins thus formed, one from each leg, unite to make one huge vein, which takes the blood into the heart.

But not to rest. For out of the heart it goes once more. And this time to a lung. In the tiny blood-vessels of the lung, the darkened, impure blood gives up some water and the waste gas it has been carrying and picks up oxygen in exchange: scarlet with oxygen, it is once more hurried back to the heart. And as I puff out air from my lungs, along with the rest of the carbon dioxide and moisture in it I puff out what has come all the way from my big toe.

So it goes on all the time without ever stopping, this *circulation* of the blood. From lung to heart: from the heart by the arteries to every part of the body: from every part of the body back to the heart again by the veins; and then out to the lungs again. If we get no oxygen, there can be no burning in our bodies: if we do not breathe, we get no oxygen: if there were no blood to carry oxygen about, the oxygen would get no further than the lungs, and that would be no use to our toes or our fingers or any of our other organs. And if the blood did not keep circulating like this, these organs would also be unable to clear themselves of waste; for the blood is also responsible for carrying the waste away to the lungs and kidneys,[1] where it can safely be cast out and got rid of.

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[1] The kidneys are not concerned, however, with getting rid of gas. They get rid of water and of soluble waste containing nitrogen. (*See* also pp. 10–11.)

CHAPTER XI

HOW ANIMALS BREATHE (i)

PLANTS BREATHE THROUGH LEAF-HOLES – BREATHING-APPARATUS OF RABBIT AND BIRD COMPARED – WHY BIRDS NEED SO MUCH OXYGEN – THE FROG'S FORCE-PUMP – SKIN-BREATHING – GILLS

ALL animals and all plants must have oxygen just as we must have it, and for the same reasons. They get their oxygen from what they live in – direct from air or from air dissolved in the water, as the case may be. And they all make the same use of oxygen when they have got it; and they all have to get rid of the waste gas, carbon dioxide, which their bodies go on making as long as they are alive. All animals and all plants must breathe.

Plants breathe through their leaves chiefly. There are tiny holes in the leaves, and the air gets into the plant through these. (*See* picture on p. 91.) Day and night the living plant is slowly, slowly breathing all the time. But, since the plant is so much less active than the animal, it doesn't need such large quantities of oxygen; and no plant makes the breathing movements of its body that show so clearly in many animals. The air just filters into the plant and the carbon dioxide filters out in exchange: the plant never pumps air in and out of itself. It is because plants breathe so inconspicuously that it is difficult at first to believe they breathe at all.

With animals it is usually much easier to show that breathing is going on; but the different kinds of animals have different kinds of breathing apparatus and they breathe in different fashions.

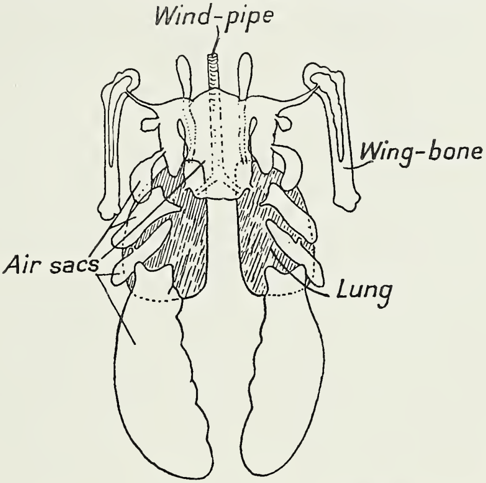
Like us, all the land vertebrates breathe by means of lungs. The rabbit and the dog and the horse have lungs; the bird has lungs; the tortoise and the lizard and the frog have lungs. All these creatures with lungs breathe air. If their lungs get filled with water, they suffocate, they drown; for though there is oxygen in the water, their lungs can't make any use of it: their lungs are made for air-breathing only. Even a whale breathes by means of lungs; for the whale, you remember, is really a land animal that has taken to the water; and you could drown a whale if you kept him under the sea long enough, so that he wasn't able to come up for a puff of air now and then.

Rabbits and horses and dogs and monkeys – in fact, all the mammals – use their chests in breathing just as you and I do. They all have a breastbone and ribs and a diaphragm, just as we have. The rabbit, just like ourselves, raises his ribs and lowers his diaphragm, and air rushes down his wind-pipe into his lungs until they are filled. Then the diaphragm rises again and the ribs are lowered, so that the chest gets smaller and the air is driven out again from the lungs, up the wind-pipe and out at the nostrils. And the same is true of the dog or the cat or the horse: it is even true of the whale.

It is rather different with the bird. Opposite is a diagram of the breathing organs of a pigeon and its right lung is also shown on p. 59. Just as with the rabbit, the air goes in at the bird's nostrils, which lie at the root of the beak. Then it goes down the wind-pipe to the lungs. In the picture on the opposite page, the lungs are the shaded part. But now, do you see these balloon things round the bird's lungs ? There isn't anything like that round the frog's lungs, or round our lungs. (*See* picture on p. 59.) These balloon things are called the 'air-sacs.' They are actually joined on to the lungs, so that when the air gets down to the chest it rushes on through the lungs and fills the air-sacs as well. Then, when the bird breathes out, the air from the air-sacs has to pass back through the lungs again before it gets to the wind-pipe and so to the nostrils and the outside world. So every time the bird breathes, the air passes twice through the lung – once on its way *to* the air-sacs, and once again on its way back *from* the air-sacs. Now, that is important.

It is in the lungs that the blood gets its chance to pick up oxygen and give away the waste gas, carbon dioxide. And in the bird, you see, the blood of the lungs gets a *double* chance to do this: it gets the first chance when the air rushes through the lungs to the air-sacs, and it gets the second chance as the air rushes back through the lungs again to the bird's nose. This double chance is very important for the bird, for it is a tremendously active animal: it uses its muscles all the time. A bird is hardly ever quite still when it is awake. Either it is flying, and then its muscles have very hard work to do; or else it is hopping or running about; or it is singing; or it is hunting for worms and feeding its young. The bird has an exceedingly active life and uses its muscles far more than most animals do. And we know that muscles won't work unless there is plenty of oxygen coming to them to set free energy. Again, because birds' muscles work so hard, the bird's body makes an exceptionally large amount of waste gas. So the double chance the blood in the bird's lungs gets, of picking up oxygen and giving up carbon dioxide, is very valuable for such an active creature; and it is the chief reason why birds don't get tired easily.

The air-sacs lie in between the other organs of the body, and, in a bird like a pigeon, bits of them pass out through holes into some of the bones. So, when a pigeon takes a breath of air, its whole body swells with the blown-out air-sacs and even its bones get filled with air. This warm air all through the body helps to keep the creature light for flying. The up and down movements of the wings pump the air in and out of the chest; and this is the more necessary since the bird has got no diaphragm like a rabbit or a man.



Modified after Heider

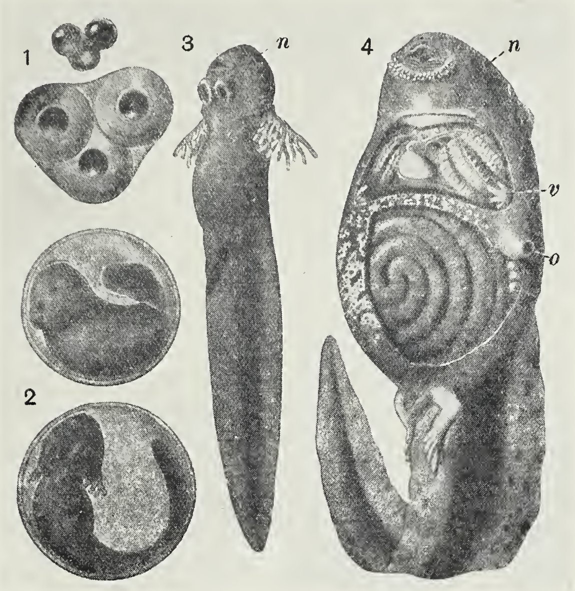
Air-sacs of pigeon.

From Dakin's *Elements of General Zoology* (Clarendon Press, Oxford)

It is interesting to compare the way a frog breathes with the way we and the rabbit do. The breathing movements of the frog are not where you would expect them to be; they don't show much in the chest. The frog has neither diaphragm nor ribs. If you touch a frog's sides, you will feel no ribs there: the sides of the chest are quite soft. So, as it has no ribs and no diaphragm, the frog has to have a different kind of air-pump for breathing. If you watch a live frog, you will see that the throat, just below the chin, is moving up and down: little panting movements of the throat are followed every now and then by a bigger gulp, as though the frog were swallowing something invisible. The frog is swallowing mouthfuls of air, pumping them in and out of its lungs by moving the floor of its mouth up and down; and the air rushes in and out of the frog's mouth through its nostrils – little holes, one on each side of the tip of the nose. The frog is a very good nose-breather; it never breathes through its open mouth, the way we do when we have a bad cold or adenoids. In fact, if the frog's mouth were forcibly kept open, the pumping business wouldn't work properly and the animal would gradually suffocate.

When the frog is in the water, it swims underneath, and it can stay down below for a surprisingly long time, with its nostrils tight shut so that water cannot get down into the lungs to drown it. Every now and then the frog comes to the surface, opens its nostrils and pumps in some air. (*See* picture on p. 35.) Then it goes down again. But the frog is able to hold its breath for a long, long while in between. That is because it also has the power of breathing through its skin. I suppose you have noticed how moist a frog's skin is ? When you touch a lizard's skin, you find that it is dry and scaly. But a frog's skin is clammy to the touch, and it is quite naked. Well, one reason why the frog has a moist and naked skin is so that it can use the skin to breathe with. Just under the skin are lots of tiny blood-vessels, and the blood in these can get oxygen from outside and give up waste gas, so long as the skin remains moist. So even if the frog's lungs are not working, the animal can carry on for a long time by using its skin instead. This power of skin-breathing is especially useful to the frog when it goes into its winter sleep in the mud at the bottom of the pond.

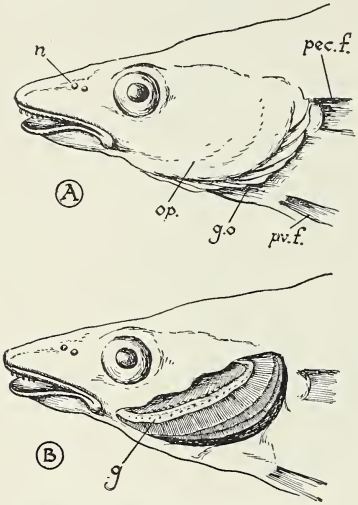
I expect you have caught tadpoles in the spring and kept them in glass jars; and perhaps you have been successful in getting them to turn into tiny frogs after about three months. If you were *not* successful, one of the reasons may have been that you didn't realise the difference in the way the creature breathes when it is a frog from the way it breathes when it is a tadpole. Next time you rear tadpoles, look very closely at them when they are about a fortnight old. You will see three little fringy things sticking out from each side of the neck. These are what the young tadpole breathes with. We call them the 'gills.' Inside the gills are tiny blood-vessels, and through the skin of the gills the blood can get oxygen from the water and give up carbon dioxide – just the way the frog's skin does. As the tadpole grows older, its gills get covered over by a sort of flap on each side. Water passes in at the mouth, and out through a hole under the flap on the left side of the body: and, as the water current flows, it washes over the gills and so the breathing goes on for a time. But when your tadpole begins to grow its frog legs, you'll notice that it keeps coming to the surface in a way it didn't do before. This means that its gills are disappearing and that it is growing lungs instead, lungs which it must fill with air from time to time if it is not to drown. If you have little bits of cork floating in your aquarium, or if you arrange sloping stones that stick up to the surface of the water, the tadpoles can now rest against these with their noses out of the water; and you will be much more likely to keep them alive right through to the frog stage when their legs are fully grown



The Tadpole. 1, three eggs: above, as they are when still in the body of the female; below, as they are in the water, each surrounded by jelly. 2, tadpoles before hatching out of the eggs. 3, young tadpole with suckers, mouth, nose opening (*n*) and outside gills. 4, older tadpole partly dissected. In 4 the heart, arteries leading to the gills as in a fish, and the gills are seen: In the abdomen is the spiral intestine. *n*, nose opening; *o*, opening from gills; *v*, beginning of front legs. The hind legs are also seen.

From Munro Fox's *Biology* (Cambridge University Press) and they come out on land to breathe air all the time like their parents. So first the tadpole is a water-breather, getting oxygen from the water through its gills; and it then turns into an air-breather, a frog like its parents, breathing by lungs – helped out at times by the skin.

Fishes always get their oxygen from the water. Fishes always breathe like young tadpoles. Again I want you to watch the goldfish in its globe: but this time don't think about the fins and the tail. I want you to notice the breathing movements. Notice that the fish keeps opening and shutting its mouth, whether it has anything to eat or not. It seems to be swallowing water; but most of the water is not going down into the fish's stomach. It is washing out through slits on the sides of the fish's neck. There are five of these slits on each side really; but you can't see them in the living fish because they are covered over by a flap lying just in front of the front pair of fins. If you watch that flap, you see it open and shut, and open and shut. The water that the fish has taken into its mouth washes out from under the edge of the flap every time the flap opens. Then the fish closes the flap, opens its mouth, takes another gulp of water, and opens the flap again. So the current of water keeps going all the time, and it gives oxygen to the blood inside the gills under the flap, and carries away the carbon dioxide.

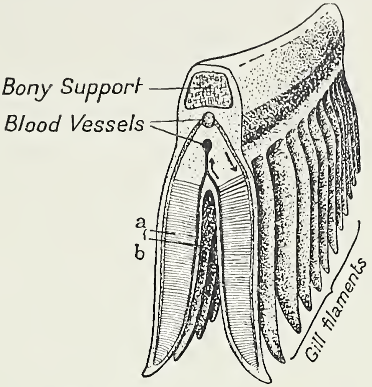


Head of a whiting. In B the gill-cover has been cut off to show the gills. *n*, nostril; *op*, gill-cover; *g.o*, gill opening; *g*, gill; *pec. f. and pv. f.*, paired fins.

From Phillips and Cox's *A First Book of Biology* (University of London Press, Ltd.)

You should get a haddock from the fishmonger and lift up its gill-flap and look underneath. Then you will see the gills easily enough. They are little soft, red tags of flesh, full of the red blood that shines through. And these tags, or 'filaments,' are arranged in a double row along a curved support called the gill arch; it is as though you had a bent comb with a double row of teeth. You can count four of these combs, and between each one and the next is the slit through which the water can pass from the fish's mouth to the outside. If you take your dead haddock, lift up the gill-flap and push a knitting-needle into the slit between any two of the combs, and then open the fish's mouth and look in, you will see the point of your knitting-needle inside the fish's mouth. That will show you that there is a real passage-way from the mouth to the outside of the neck. Or if you pour water into the dead fish's mouth, it will trickle out through these slits and out from under the gill-flaps.

It is important to notice that the gills must be kept wet if the fish is to go on breathing. If a fish is taken out of water, its gills dry up, and gradually the fish will die of suffocation because it can't get oxygen. The air is full of oxygen, but the fish can't make any use of it; and one reason is that its gill-filaments are getting all dry and stuck together.



A piece of fish's gill cut through and seen from the cut end. Greatly enlarged.

From Goldschmidt's *Ascaris* (Julius Springer Verlagsbuchhandlung, Berlin)

CHAPTER XII

HOW ANIMALS BREATHE (ii)

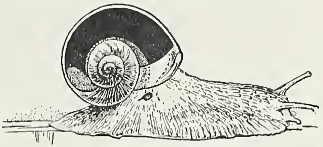
THE PERFECT SKIN-BREATHER – THE SNAIL'S LUNG IS ON ITS BACK – POND-SNAILS – THE INSECT'S AIR-TUBES – COMPARE INSECTS WITH BIRDS – THE WATER-BEETLE AND THE CADDIS

ALL the animals whose breathing we have been considering are vertebrates. In this chapter I shall go on to the invertebrates, the animals that have no backbone and are made on quite a different pattern from ourselves. Most of the invertebrates are small creatures compared with the vertebrates; but however small an animal is, it must have oxygen and it must get rid of its waste gas.

Among the invertebrates, the earthworm is a good example of an animal that breathes *entirely* through its skin. It has neither lungs nor gills. You know how damp an earthworm feels when you touch it? Well, because the skin is so moist and thin, it is used by the earthworm as a breathing organ, for just underneath is a network of very tiny blood-vessels filled with red blood. The red stuff of the blood comes so near the surface of the animal's body that oxygen from the air can easily pass through to it: the blood seizes the oxygen and carries it away in the vessels to the other parts of the body that need it. In exchange for the oxygen it gets through the skin, the earthworm's blood gives up carbon dioxide to the air. There are no special breathing movements to watch in the earthworm, but the exchange of gases is none the less very complete. The whole surface of the body is used instead of a lung.

But please notice that these gases could not get in and out through the skin unless that were moist. If an earthworm's skin gets dried up, the poor creature cannot breathe, and so it dies of suffocation.

Though the snail's skin is even moister than the earthworm's, the snail is not a skin-breather. The snail's moist skin is ever so much thicker than the earthworm's, and the snail's pale blood cannot come so near the surface as the red blood of the earthworm does. For its breathing, the snail depends on a kind of lung it has on its back. In the chapter on crawling we didn't consider much about the snail except its muscular, rippling foot. But I think I mentioned that even when the foot and head are all stretched out, the more delicate organs still lie sheltered in the shell. One of these delicate, hidden organs is the lung, by means of which the snail breathes. Next time you get a chance to look at a snail when it is moving along, don't so much think about the way it crawls, but look this time at the place where the shell rests on the front part of the body. You will see that the edge of the shell rests on a sort of pad or thickening: and on the right-hand side of the animal there is a hole in the pad. This hole opens into the lung. If you had a dead snail, you could break away the shell bit by bit, and then you would see the outside of the lung. It is a sort of greyish bag, made of very thin skin, and it is lined with small, branching blood-vessels in which lies the colourless blood.

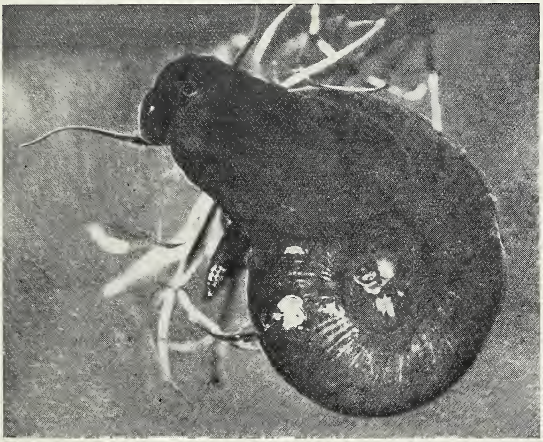


Drawn by L. R. Brightwell

Part of the snail's shell is removed to show the position of the lung (black).

From Andrade and Huxley's *Science and Life* (Basil Blackwell)

The lung gets filled with air coming in through the hole on the right-hand side of the animal, and immediately the blood in the little vessels there gives up its waste gas and picks up oxygen in exchange, for the use of the snail's body. Then the stale air is pumped out of the hole and a fresh supply rushes in. The snail has no ribs or breast-bone or diaphragm to help empty and fill its lung. It does the pumping by heaving its back up and down as it crawls along. I mean, when it heaves up its back, that squeezes the lung and presses the air out: and when it lowers its back, the lung expands because it has more room, and the air rushes in through the hole to fill it again.



Photo, W. S. Berridge

Trumpet snail crawling up the side of the aquarium.

The kind of snail I meant, and the kind you were thinking about probably, is an ordinary garden snail. But quite a lot of snails live in the water.

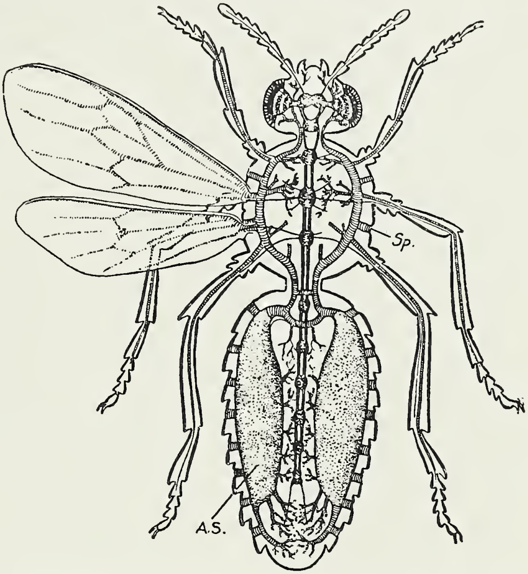
These are smaller kinds than the garden snail, with brown shells of different shapes. You will find some in almost any pond; and if you set up an aquarium, you would do well to keep some of these snails in it. For one thing, they are very useful as scavengers: they eat up the rubbish and keep the glass clear of the green scum that grows on it. But another reason for keeping pond-snails is that they are interesting to watch. Though they live in the water, they have a lung. Like the land-snail, the common pond-snail and the one called the trumpet-snail must have air to breathe. They can't make use of the oxygen in the water, any more than you or I could. So every now and then these snails have to come to the surface to get a lungful of air through the little hole on the right-hand side of the body. You see them then moving about upside-down on the surface of the water, and if you listen closely you may sometimes hear a little 'pop' as a snail opens the hole to its lung. Then they go down again and crawl about feeding; and the air-supply lasts them for quite some time, for a snail is not a very active animal and so it doesn't need a great deal of oxygen to keep it going. Just the opposite from a bird or an insect.

For what is true of a bird is also true of an insect. About its being so tremendously active, I mean, and therefore needing such a quantity of oxygen. If you watch bees collecting their food from the flowers, you can see how energetic they are. Hour after hour after hour they work, sucking up nectar, brushing off flower-dust, flying about at a great pace from one plant to another; this goes on all day long until the sun sets and the air turns chilly. The bees never rest while the light lasts and the air is warm.

Someone once said that 'insects are the birds of the invertebrate world': and in a way that is true. Insects are like birds because they have wings and can fly: but they are also like birds because of their intense activeness.

You can see, then, that since insects work their muscles very hard, this means they need a lot of oxygen. So we find that the bee and all the other insects have a splendid breathing apparatus. This breathing apparatus of the insect is quite different from any of the ones I have described. An insect cannot breathe through its whole skin like an earthworm, because, as you will remember, it has an outside skeleton through which it would be impossible for gases to pass in and out.

The picture on p. 73 is supposed to show a bee with its back taken off so that you can look at its inside. Do you see those tubes with cross-markings on them? They run all through the bee's body – right to the hind end, and forward into the head, and down each of the six legs, and even out into the wings; and they give off little branches as they go. In the bee, two of them are swollen out into bags, marked A.S. in the picture; these are reservoirs for air. Now, do you notice that the reservoirs, the air-sacs of the bee, have very short tubes leading from them to the surface of the body? Each of these tubes opens to the surface by a hole, so that air can get in from outside. Further forward in the body, you can see more of these openings: one of them is marked '*Sp*' in the picture. The holes to the air-tubes have little doors that can open and close, and so let air in and out as the insect breathes. When you were watching a wasp on the jam, did you ever notice how the hind part of the body seems to be panting? That is the wasp breathing. By these panting movements it is squeezing air in and out of its air-holes through the little doors in the sides of its body, and so in and out of the air-tubes that go all through its inside. You might compare these air-holes of the insect to the port-holes in the sides of a ship, which let air in and out of the cabins: there is a row of port-holes along each side of the ship, and each port-hole has a little round glass door which can be opened and closed.



Air-tubes and air-sacs inside an insect's body. *Sp.* stands for spiracle and *A.S.* for air-sac.

From Stempell's *Repetitorium der allgemeinen Zoologie* (Verlag von Gebrüder Borntraeger, Berlin, W. 35)

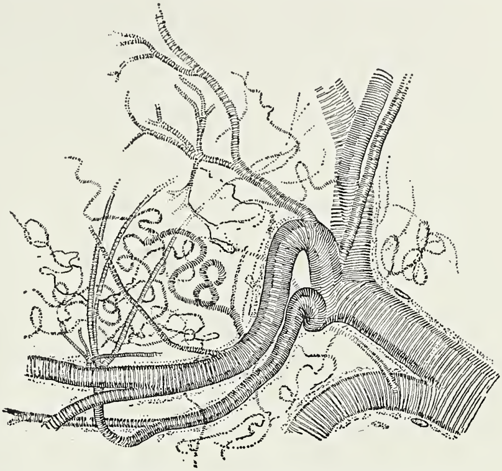
Now you see why a wasp gradually suffocates if it falls into the jam or gets its body all smeared over. The air-holes get stopped up with the jam, so the wasp can't breathe even if its head is free.

The air-tubes branch inside the body, as you can see in the picture. The branches branch again and again and again, until they are tiny twigs; and every one of these twigs gets filled with air from outside, so that the oxygen is carried right in to every part, even the very tiniest. On p. 75 is a picture of what you would see if you looked at a scrap of a blackbeetle's inside under the microscope. However small the morsel of muscle or fat, it is all full of air-tube twigs, which show like silvery lines. With the microscope you can see that a spiral thread is closely wound round inside each tube: this is to keep it open. You know how sometimes a rubber gas-pipe has a wire wound round it in a spiral, so that if by mistake you tread on the tube, you are not so likely to squash the tube flat and stop the gas getting through to the burner. Well, it's the same idea here. The spiral thread holds the air-tubes open so that they won't get stopped up when the insect's muscles press against them; the oxygen can always get through to keep the fires of life burning.

When the insect is running or flying, its body warms up, and this warms the air in the tubes so that it expands. This probably helps to buoy up the body of the flying insect, just as the warm air in the air-sacs of the pigeon may help to keep the bird up. But the really important thing to notice is that in both these tremendously active creatures – the insect and the bird – the breathing apparatus is specially arranged to yield a great deal of oxygen very easily. The apparatus is different in the two cases; but the result is much the same. These two kinds of animals can go on and on and on, flying and running about for hours without getting too tired. All this oxygen they so easily get enables them to burn lots of fuel and so to keep the engines of the body running fast and well; and the engines don't get clogged, because the waste that is formed in the burning gets carried away so easily and so completely.

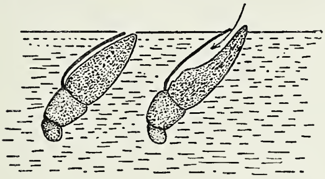
The insects I have mentioned – the bee, the wasp and the blackbeetle – live all their lives in the air. But many insects live under water: and some of these – some of the big water-beetles, for instance – have to come up to the surface every now and then for a supply of air to go on with. On the opposite page there is a little picture of a water-beetle getting air. This is just a diagram, you understand: it is not supposed to be a portrait of the beetle, but merely a simple sketch of the body without legs or feelers. The beetle is shown with its body and head hanging down into the water from the surface. The thick black line on the beetle's back is meant to be the very thick, hard, front pair of wings. And when the beetle comes to the top, it sticks out the end of its body above the water and raises these wings a tiny bit, and air gets in beneath them, where you see the little arrow going. Then the beetle dives, carrying under its wings the precious air-bubble as a store of oxygen on which its air-tubes can draw for a time.

But if you keep water-insects in your aquarium, you will soon notice that they don't all come up for air like the water-beetle: quite a lot of them stay down below all the time. Caddis-worms, for instance. What we call the caddis-worm is really the caterpillar stage, the *larva*, of an insect not unlike a sort of moth. While it is in the larval stage, the caddis lives always under water. You should certainly collect caddis-worms for your aquarium because they are ever so common in ponds and they are very interesting to watch. They make for themselves a most peculiar sort of coat of sand-grains all stuck together, or of little bits of stick, or of little bits of leaves. Overleaf, marked *a*, is the caddis-worm; and alongside it, marked *b*, is its coat taken off. I call it a coat, but perhaps you would rather call it a movable house, for the animal can withdraw completely inside it and shelter from its enemies in the pond: the enemies just see the sand-grains or the little bits of stick and they don't guess that a living insect is hiding inside, so they go away and leave the caddis alone. If you very gently take a caddis out of its house and put it in a saucer of water with some tiny coloured beads or fragments of coloured glass, it will make a new house for itself out of these things. I gave a caddis some red, white and blue beads the other day, and its house looked most patriotic when it was finished!



Part of inside of cockroach showing air-tubes under the microscope.

From Borradaile's *Manual of Elementary Zoology* (Oxford University Press)

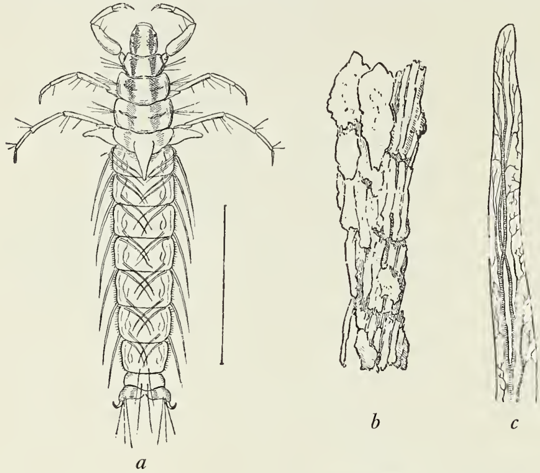


After Schönichen

Water-beetle getting air.

From Dakin's *Elements of General Zoology* (Clarendon Press, Oxford)

The house is always shaped like a tube, open at both ends; and, when the caddis is walking, its head and its six legs stick out through the front-door. There is also a back door; and from this back door water is constantly streaming out. Water goes in at the front door and out at the back door, and what keeps the water flowing through the house is the wriggling of the caddis inside. This stream of water through the house is a ventilating current. The water that comes in at the front door is fresh water with oxygen in it, and the water that comes out at the back door is stale water with carbon dioxide in it. This means that somewhere inside the house breathing has been going on. Now look again at the picture of the caddis, and notice these things like hairs on its back. These are its breathing organs, and they are washed all the time by the water that rushes past them through the house. One of them, marked *c*, is shown to the right in that picture, as it would look under the microscope. And when it is magnified like this, you can see that there are branching air-tubes inside it.



Drawn by A. R. Hammond

Caddis-fly larva (grub). *a*. Larva. *b*. Its house. *c*. One of its tube-gills.

From Miall's *The Natural History of Aquatic Insects* (Macmillan & Co., Ltd.)

While it lives in the pond, the caddis is one of those insects that get its oxygen from the water. The hair-like things with air-tubes inside are made of very thin skin; the oxygen from the water can get through that, and the waste gas can get out. Lots of other insects have their young stages living under water in this way, and getting oxygen from the water instead of from the air. Dragonfly young and the young of mayflies show the same sort of thing, and it is interesting to keep them in aquaria and watch how they live. (But I must warn you never to put dragonfly larvæ along with other pond-animals, for they are fierce, flesh-eating creatures, and they will attack and devour things as large as tadpoles even. Mayfly larvæ, like caddis-worms, are quite harmless.)

CHAPTER XIII

FOOD, AND WHY ANIMALS EAT IT

WHAT IS 'STARVATION' ? – STORES OF FUEL IN THE BODY – FOOD AND FOOD-STUFFS – THE THREE GREAT FOOD-STUFFS – WHAT THEY ARE USED FOR – DIET – NECESSARY EXTRAS – WATER IS ALL-IMPORTANT

WHY do animals eat food ? Of course they eat so as not to starve. But 'starve' – what does that mean exactly ?

Animals, like men, *can* go on for quite a time without food, so long as they get plenty of water to drink. The camel will go for days without food when it is crossing the desert. But the camel is rather an exceptional beast in many ways, and it can live for a time quite actively on the fat stored in its hump. Generally speaking, healthy animals are very dependent on regular meals. The only ones that fast for choice are the kinds that go into a winter sleep – bears, for instance, and squirrels and dormice. For more about these winter-sleeping animals you must look up Chapter XVIII. Here I would just point out that during their winter sleep such animals are very inactive indeed, and so require comparatively little fuel to keep the fire of life smouldering.

That is what it really comes back to – *fuel.* If an animal is starving, this means its body has used up all the available fuel and can't get any more to go on with. The animal ceases to be able to run about, because there is nothing to burn in the muscles that should move its legs: it breathes with difficulty, because the muscles that should move its ribs and diaphragm are also short of fuel: its brain and its nerves work more and more feebly because they are getting so little nourishment and such a bad oxygen supply. In fact, everything gradually goes wrong with the animal's works. And finally, even its heart stops beating. That is the end. The animal dies of starvation.

For some time before the last stage comes, it has been living on its own fuel-stores. For some time there is quite a lot of sugar to be got from its own liver, for instance; and for some time there is plenty of fat in its body, especially just under the skin. On these stores the animal draws for a while, and as it does so, its body wastes away: it gets thinner and thinner. But an end must come to these supplies, and the weaker and colder the animal gets, the less able is it to go a-hunting for the fresh fuel that would put matters right.

The animal, then, must have food if it is to go on living – if it is to move about and take in news of the outside world and repair the parts of its body that wear out.

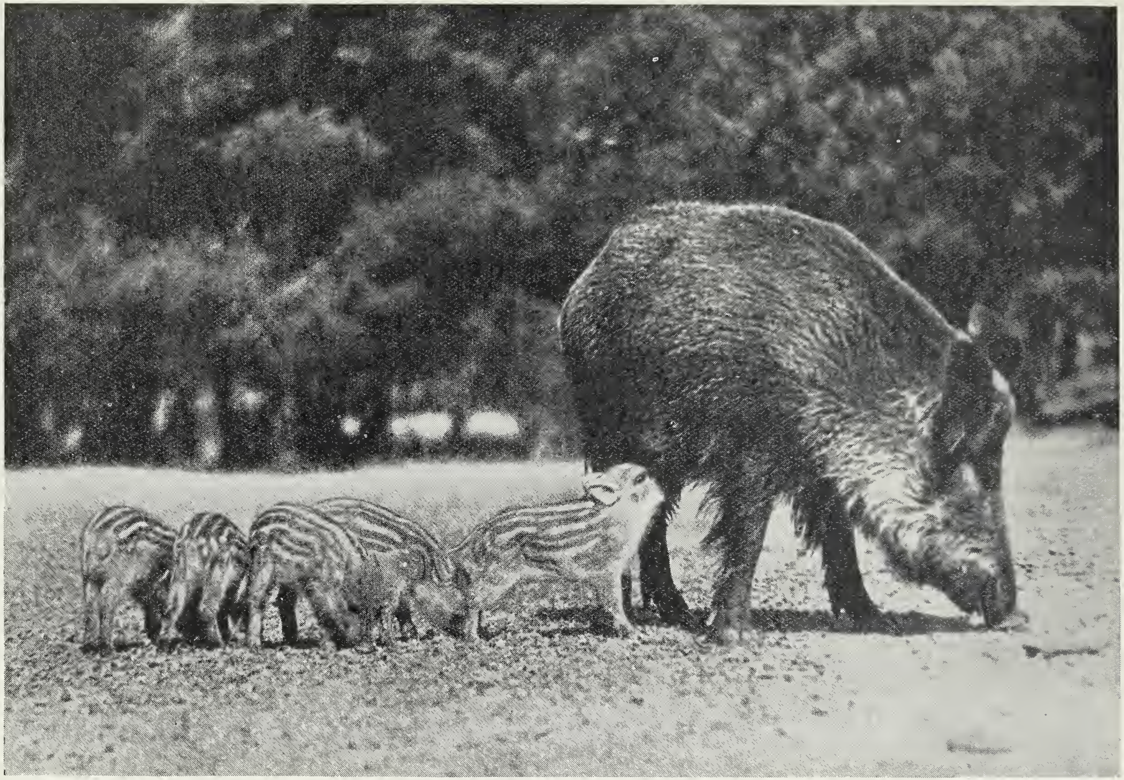
Now, what is 'food' ? Again you may think that this is a silly question. You will say that food for a dog is bones and meat or dog-biscuit: food for a cat is liver and fish and milk: food for a rabbit is dandelion-leaves and lettuce: food for a horse is hay: food for a spider is flies. As soon as I name the animal, I have no doubt that you can tell me what its food is.

It is perfectly true that each sort of animal has a particular kind of food that it prefers; and it is perfectly true that the rabbit couldn't digest the dog's dinner even if it were terribly hungry, and the dog couldn't live on hay. So you may not at once believe me when I say that all these different animals are really eating the same things.

You will agree, however, that the food animals eat is either the flesh of other animals or else it is part of a plant. And I explained in Chapter III that the stuff of which all flesh and all vegetable matter is composed is essentially the same. The same chemicals – carbon, nitrogen, hydrogen and oxygen are found in them all: and in addition, there are other chemicals in different amounts – sulphur, phosphorus, and extras like salts of calcium, magnesium and iron. Now surely, since the bodies of animals and plants are composed of these comparatively few things, 'food,' whatever it looks like, must also contain them, and them only?

Notice that word – 'composed.' The animal (unlike the plant) cannot make use of pure carbon or any other of the simple ingredients in a pure state. (I know I have said this before; and I warn you that I shall probably say it again, for it is a very important point.) The animal's food consists of what we call 'food-stuffs'; the food-stuffs are 'compositions'; they are made of three or more of the important elements put together.

There are three main kinds of food-stuffs that all animals must have in their diet, whether they are flesh-eaters or vegetarians. The first kind is called *carbohydrate*. Typical carbohydrates are things like starch and sugar. Every time you eat a potato or swallow a spoonful of honey, you are feeding on carbohydrate. Carbohydrates are composed of carbon, hydrogen and oxygen.



Photo, F. Frankenhaeuser

The wild boar's family have a meal.

The second kind of food-stuff is called *protein*. Proteins have carbon, hydrogen and oxygen in them; but they also have nitrogen and a little sulphur. Protoplasm itself, the living stuff of the animal body, is largely protein. When you eat lean meat, you are eating dead protoplasm and getting lots of protein. The white of an egg is also protein. There is protein in milk, and you get it concentrated in cheese. The living stuff of the plant is also mainly protein, and the vegetarian gets his protein by eating plants. The trouble about eating plants for protein is that there is little of it in proportion to the carbohydrates; so the vegetarian animal has to swallow larger quantities of food than the flesh-eater does, in order to get enough protein. That is to say, if it is eating the leaves and stalks. Protein is more concentrated in certain underground parts of the plant, and in the seeds: nuts, beans, peas and lentils contain a lot of plant protein for their size.

The third kind of food-stuff is called *fat*. Here again there are just three chemical elements – carbon, hydrogen and oxygen. By fat, I don't mean only the cream-white stuff you get in streaks through meat or as suet. I mean also butter, margarine, and oils such as you get from cod's liver and from certain plants, especially from nuts: that sort of oil is just liquid fat.

Of course, we seldom get any one food-stuff quite pure. When you eat meat, you usually eat some fat with the lean. When you eat bread or beans, you are eating starch as well as protein. When you eat an egg, you get protein and fat mixed. And when you drink milk, you get all three food-stuffs, plus water: which is why milk is such a perfect food, and why all mammals feed their young on it before these have teeth to bite food with.

In the last paragraphs I have written 'you' most of the way; and I know that the chapter is entitled 'Food, and why Animals eat it.' But what is true of animals' food is equally true of our own. We need the same food-stuffs as they do, and for the same reasons. Only we happen to be what is called 'omnivorous' – that is to say, we can eat pretty well any mixture of the essential food-stuffs, whether they come from animals' or plants' bodies. Whereas most other animals are either flesh-eaters (carnivores) *or* they are plant-eaters (herbivores).

The next thing to notice is that the three great kinds of food-stuffs have different uses in the body. They can all be burnt to give energy, but the carbohydrates are chiefly used for that. It is the burning of sugar by oxygen that enables the muscles to do their work; and men or animals doing hard physical work must have lots of carbohydrate. It need not be swallowed in the form of sugar: in fact, animals usually take their carbohydrate in the form of starch, and then their bodies turn it into sugar and pass that on to the blood, which carries it all about the body. We'll come on to that again when I explain about digestion in another chapter. The point to notice here is that carbohydrates – things like sugar and starch – are the food-stuffs most used for freeing energy. And when they are burnt, heat is also given off and that warms the body up nicely.

Fats also give energy when they are burnt in the body, but they give off a great deal more heat in proportion. So fat is a food-stuff your body especially needs in cold weather.

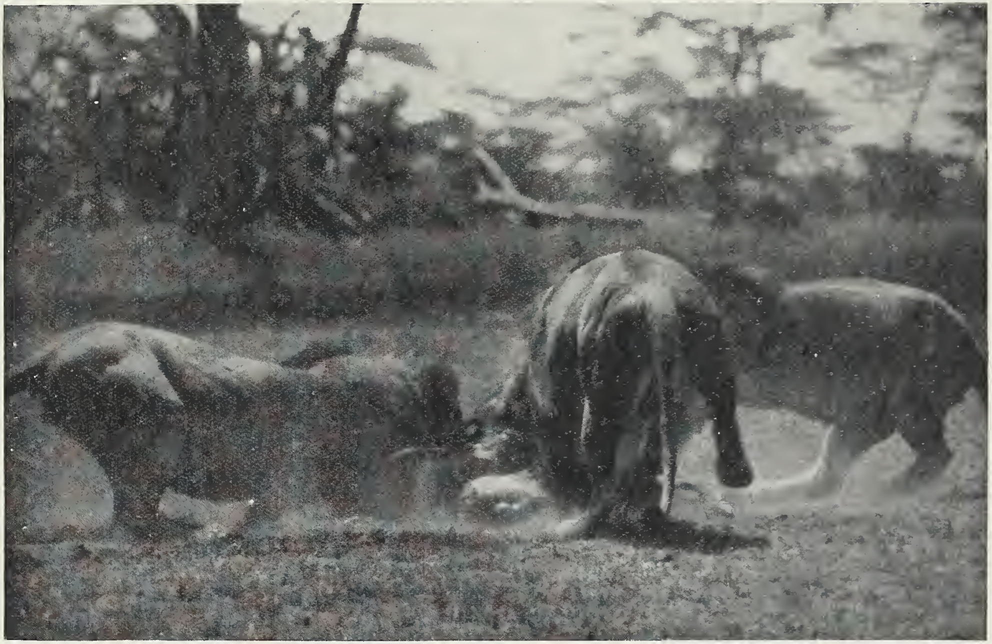
Proteins are less used than the other food-stuffs for burning. Their main use is in body-building. The body repairs its worn-out parts chiefly with protein.

Now you begin to see that it is not enough to stodge yourself with one kind of food-stuff only. You might feel quite satisfied after eating a pound of chocolates, but you wouldn't have been properly fed. You must have a mixture of food-stuffs in your food if you are to have a really satisfactory diet, because your body needs fuel and repairing stuff if it is to work well. For human beings, men of science have worked out just what the right proportions should be *at different ages*. The proportions must be different for other animals, of course, and we don't know so much about that; but, if they are living in a wild state and are free to choose their own food, animals seem to know very well what the right proportions are for themselves.

The diet is not complete even when we have put into it the right proportions of carbohydrate, fat and protein. The animal body also needs lime for building bones, and iron for helping to make blood, and various other mineral salts in small quantities. And in addition it must have things that are called 'vitamins.' We and the animals take vitamins in very, very tiny quantities in our food, and they are not actually 'food.' But they are immensely important, because if they are not in what is swallowed, the body cannot make proper use of the rest. If you are short of vitamins, you don't digest well, and you catch cold easily, your bones won't form properly, you may develop skin disease, or your nerves will be all out of order. Vitamins are found in the liver of certain animals (when you swallow cod-liver oil, you are getting vitamin as well as fat): they are found in that perfect food, milk: they are found in green vegetables and in fruits. Human beings ought always to eat plenty of green salads, and fruits like oranges and lemons, if they want the vitamins that keep them healthy. The cat is a carnivore; but haven't you noticed how your cat goes into the garden and eats a few blades of grass now and then? The dog does the same thing. And wild carnivores, like lions and tigers, get their plant stuff by eating the insides of the herbivores they kill: the lion doesn't eat only the flesh of the zebra; he also eats what the zebra has just eaten, and that is partly-digested grass.

Always in the diet there must be plenty of water. Protoplasm contains a lot of water, and as that gets used up, it must be replaced. Moreover, everything inside the animal must be kept moist if the works are to run well. Now, water is lost with every breath of air that leaves the lungs. Water is carried away from the body by the work of the kidneys. Water is passing out all the time through the pores of our skin. All that must be replaced. A grown-up person should swallow about three pints of water a day. I don't say that it need be plain water; some of it could be tea or coffee or milk.

The animals depend on water at least as much as we do. The camel seems to go without water for days and days, but that is because it has a special arrangement of little water-sacs in its stomach, and it fills these up by taking a tremendous drink before it starts on its journey. When you are putting out crumbs for the birds in winter, don't forget to give them a little water as well if the frost is severe, for they may have difficulty in getting enough water to drink: it is not only in hot countries that animals die of thirst. Birds, of course, can get a lot of water by eating juicy berries, and many animals, especially in hot countries, depend for their water-supply on the fluid in the bodies of the insects they eat: they get their water at second hand, you might say.



Photo, Capt. F. W. Hudson

Lions Feeding.

From *Nature in the Wild* (Country Life)

CHAPTER XIV

THE FATE OF A MEAL

THE FOOD-CANAL – THE NAMES OF ITS CHIEF PARTS – HOW THE FOOD IS MOVED ALONG – THE FOOD IS GRADUALLY CHANGED – WHY YOU FEEL SLEEPY AFTER A BIG DINNER – THE BLOOD CARRIES FOOD AS WELL AS OXYGEN – THE LIVER AS A FILTER – THE RABBIT'S APPENDIX

A GREAT deal has to happen to the food an animal eats before it can be used for fuel or for body-building.

You swallow bread-and-butter and jam for tea, and you think no more about it, except that now you feel comfortable and satisfied. Some of that food is becoming part of you, and a lot of it is helping you to keep warm and giving you the power to move about: but of what is happening inside you to make these things possible, you feel nothing if you are in good health.

When I was a very small child, I remember some grown-up person told me that the food I swallowed was fuel to be burnt in my body. I took this quite literally, and I imagined that I carried about inside me a roaring fire with flames that consumed my bread-and-butter and jam. I imagined the fire blazing away in a shiny black grate somewhere in my abdomen, all complete with poker and shovel and tongs alongside and a nice red hearth-rug in front: and I supposed that the meal I had eaten fell down my throat into the fire, just as soot might fall down a chimney. What happened to it after that I had no idea.

By the time you have finished reading this chapter, I hope you will know a good deal more than I did about what happens to a meal. And what I am going to tell you is true of animals as well as of human beings. When a cat has a meal of liver, and a squirrel a meal of nuts, the liver and the nuts are treated by the cat's inside and by the squirrel's inside in very much the same manner as the bread-and-butter and jam are treated by the inside of a human being.

The food we swallow does not drop down on top of the heart and lungs and kidneys and the other organs inside us, any more than it drops down into a fire-place, as I so foolishly imagined when I was young. It finds itself in a tube that runs right through the body from one end to the other. There are two openings to the tube, the mouth at one end and a hole called the anus at the other. Outside the tube, and wrapping it all closely about, are very small blood-vessels in great numbers, with blood flowing along through them. Now, what has to happen is that somehow the food in the tube shall get through into the blood in these little vessels. From there the blood will carry it away to where it is needed in the body.

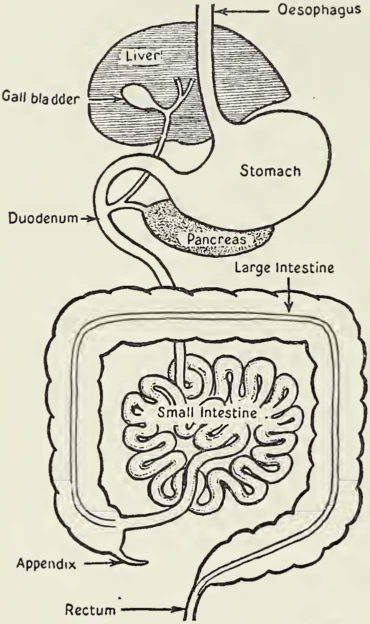
Water can easily get through the wall of the tube into the blood; and if there are salts in the food, they will also pass straight through with the water and be carried away. But practically none of the rest of the meal can do that when it is first swallowed: it all has to be changed first. This changing of the food is what we call 'digesting' it. Digestion is the business of changing the complicated food-stuffs into simpler things that will seep through the wall of the tube into the blood. Protein, starch, cane-sugar, and fat – all present in the bread-and-butter-and-jam meal – have to be simplified, digested, before we can get any benefit from them.

The name given to the tube is the 'alimentary canal.' The alimentary canal of an animal is very seldom straight, except at the beginning and for a short way near the end, for in most animals it is so much longer than the body it lies in that it has to be elaborately coiled up. The intestine of a man is about eight yards long: and even in a rabbit the intestine measures as much as two and a half yards. The canal is not the same width all the way: in some parts it is wider, in others it is narrower. For convenience, we give different names to the different parts of the canal, just as different names are often given to different parts of a long winding street running through a big town.

The alimentary canal begins as the *inside of the mouth*, where the teeth lie and the tongue: then it gets rather narrower and goes down the neck and through the chest as the *gullet* or *œsophagus*. Once it has passed the diaphragm, it is in the abdomen: here it suddenly widens very much and we call it the *stomach*. Beyond the stomach it narrows again as suddenly, and for a length of many feet it is known as the *small intestine*: then it widens once more and this wider but shorter part is spoken of as the *large intestine*. The last part of all is narrower again and is straight at the end: this part is the *rectum*. The rectum opens by the anus. Except at the two ends, there is only one gateway that can be closed, and this lies just where food from the stomach passes into the small intestine.

There are some extremely important, though narrow, side-streets leading off this main one: I use the word 'street,' but they are blind alleys. There are several very tiny ones opening into the mouth: if you could walk along these, you would find yourself in the places where the spittle, the saliva, is prepared. Then there are two larger ones further down; one ends in the liver and the other ends in the sweet-bread (pancreas). They both lead off from the small intestine, a short way beyond the stomach gate.[1]

From mouth to anus the food moves slowly, slowly along; and, as it goes, it gets gradually changed: and it becomes less and less in amount, for all the changed part is passed through the walls of the tube to the blood-vessels. What cannot be digested collects finally in the rectum, and from time to time is passed out at the anus. The indigestible remains of the food should be passed out once a day by every human being who wishes to keep healthy. If that stuff stays inside the canal, you can understand that there is risk of blockage: and, what is as bad, if not worse, it decays and becomes highly poisonous to the body.



Drawn by L. R. Brightwell

Alimentary canal.

From Wells, Huxley and Wells' *The Science of Life* (Cassell & Co., Ltd.)

Now let us follow the meal's journey in more detail. The food that has been bitten off by the front teeth is munched and munched by the back teeth, and it is rolled about by the tongue and mixed thoroughly with the spittle or saliva. When the food comes into the mouth, much more saliva than usual is poured in there than when the mouth is empty: and even the sight or the smell of food is sometimes enough to start the saliva flowing in. You know how your mouth 'waters' when you see chocolates, or when you smell the appetising smell of baking bread ?

It is very important that the food should be properly chewed. One reason is that, the smaller the pieces become in the mouth, the easier it will be to change them chemically further along in the alimentary canal, for more surface will be offered to the digestive juices. And another reason is that the saliva not only makes the broken-up food moist, and so easier to swallow, but also begins the work of digestion. In human beings anyway, saliva has the power of changing starch into sugar: starch cannot get through to the blood, but a certain kind of sugar (grape-sugar or 'glucose') can. There is a lot of starch in bread, from the corn-seeds that are used for making flour. You will notice that if you chew bread for some time very carefully, it begins to get a sweetish taste: that means that the work of starch digestion is beginning already.

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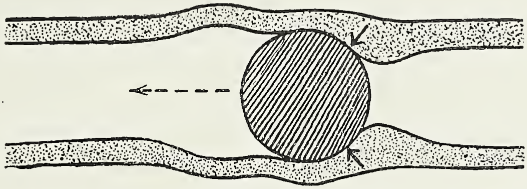
[1] In some animals, as in the frog, they are joined.



Drawn by L. R. Brightwell

How food is squeezed along the alimentary canal.

From Wells, Huxley and Wells' *The Science of Life* (Cassell & Co., Ltd.)

When the chewed food is well moistened, it is rolled into a ball by the tongue and then swallowed. It passes over a sort of drawbridge that lets down for it across the top of the wind-pipe, and beyond that drawbridge lies the gullet. (When you choke, what happens is that the drawbridge has not worked quite properly, and some of your food has 'gone the wrong way' and has got by mistake into the wind-pipe. If the food gets into the wind-pipe, of course the passage for air to the lungs gets blocked and there is danger of suffocation. The violent gasping and coughing of a choke are the body's efforts to force the food out of the wind-pipe back into the mouth.)

The moment the food gets into the gullet, the gullet seizes it firmly by muscular narrowing of the walls, and pushes it along and along towards the stomach. When I said on p. 86 that the food 'moves' along the alimentary canal, that was not quite correct. The food is *moved*, pushed, squeezed along, by the contraction of the muscles in the wall of the tube. If you understood my description of the way the muscles work in the earthworm's body-wall, you will better understand how the muscles work in the alimentary canal. Here also there are two layers of muscle, with the threads of one coat at right angles to the threads of the other coat: and here also a contraction beginning at one end passes all the way along to the other end in a sort of wave. The effect here is not to move the alimentary canal along, of course, for the alimentary tube is a fixed thing. But it is to pinch in and take a grip on the food-ball and thrust it gradually further and further down.

The gullet is not a digesting part of the alimentary canal, and the food is not changed further until it gets into the wide part called the stomach. When food reaches the stomach, then immediately the doorway from the stomach to the small intestine closes itself, as you might close the opening of a bag by tying a string tightly round it. And now for some considerable time the food stays in the stomach, and is driven to and fro by the movements of the muscular walls. The inside lining of the stomach meanwhile pours a fluid on to the food, an acid fluid called the gastric juice. This gastric juice is very important indeed for digestion. Its special duty is to begin to change the proteins and make them simpler. There is a good deal of protein in bread (especially brown bread), from the corn-seeds of which flour is made; and as a meal stays churning about in the stomach for one to four hours (the length of time is rather different in different people, and depends too on what the meal consists of) there is plenty of time for the protein to be well mixed with gastric juice and simplified a bit.

When that part of the digesting is over, the gateway from the stomach opens and the food, looking now rather like thick, whitish soup, is squirted through into the small intestine. The stomach door closes behind it, and the meal goes on along the remaining yards of muscular intestine, which squeeze it down and down towards the rectum. Almost as soon as the food reaches the intestine, the liver and the pancreas get busy and pour out special juices of their own, which trickle in on the food from those two small side-passages I spoke of. The bitter, greenish juice from the liver (what we call 'bile') is especially responsible for helping to change the fat in the food: in the meal we are considering, that would be the butter you spread on the bread. The lining of the small intestine itself and the juice from the pancreas do all the rest of the work of digestion: and it is not a light job. Such starch as has escaped the saliva is changed to sugar that will pass out through the wall into the blood: the cane-sugar of the jam you put on the bread-and-butter is changed to grape-sugar and fruit-sugar: the partly-changed proteins are now finally broken up into still simpler things called amino-acids: and the fat, the butter, is finally reduced to tiny, tiny beads of oily stuff. Now at last everything is digested and ready for the blood. The changed food begins to seep through the walls of the alimentary canal and goes into the little vessels that wrap it round. And away it is whirled in the blood-stream. . . . . Have you ever noticed that after a big dinner you feel sleepy and perhaps rather chilly? That is because so much of your blood has gone to your stomach and intestines for a time. The outer parts of your body haven't so much blood in them and so feel colder, and your brain doesn't work quite so well because less blood is going to it. So it is a good plan to rest after a substantial meal: you are giving your body a chance to do the digesting and food-absorbing business as thoroughly as possible and without too much strain. If you go rushing about after the meal, or if you try to work hard with your brain then, the body has to send to your muscles and your brain blood that is badly needed at the stomach and intestine.

From the alimentary canal, the blood takes the food first to the liver, which acts as a sort of filter. Coming straight from the walls of the alimentary canal, the blood contains, as well as the digested food, certain stuffs (such as ammonia) which would be harmful to the body. So the liver takes these out as the blood filters through it, and they are changed a bit and sent to the kidneys, and the kidneys pass them out of the body with water in the urine. The liver also takes from the blood a lot of the sugar from the digested food, and turns it into a kind of starch and stores it up: then the liver doles this out to the body later on, once more in the form of sugar, as it is required. The liver is a most extraordinary organ: it has so many different duties. I have now mentioned three of them – to make a digestive juice, the bile: to remove poisonous things from the blood and send them to the kidneys to be got rid of: to act as a store-house for carbohydrate food-stuff.

By the time the large intestine is reached, most of what is digestible in the meal has been passed through to the blood. The remaining stuff, as it comes into the large intestine, is still very fluid because of the juice that has been mixed with it. This water is now drawn off through the walls of the large intestine into the blood-vessels round it, so that the left-over remains of the meal becomes pretty solid and in a state to be forced out of the body through the anus.

There is one thing leading out from the alimentary canal that I forgot to mention. It is the *appendix*. I expect I forgot it because I really don't know what it is for in the human being. The appendix is a short blindalley leading out from the place where the small intestine ends and the large intestine begins. For some reason, the appendix of the human being is liable to become inflamed, and then he is said to have 'appendicitis.' If the inflammation does not quieten down with rest and proper treatment, the doctor may have to cut it out. It doesn't seem to be a necessary part of the food-canal (in a human being, anyhow) and you can get on perfectly well without it. If you have been so unfortunate as to have that painful inflammation of the appendix, you will remember that when the doctor came, he pressed with his hand against the lower right-hand side of your abdomen and asked if that hurt specially. This is the place where the appendix lies.

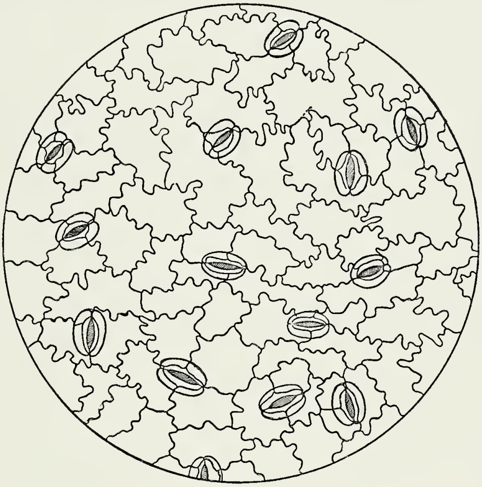
In the rabbit, the appendix is much longer in proportion than it is in us, and it lies at the far end of a long, very wide side-street, as you can see in the picture on p. 123. In the rabbit, and in the horse, and probably in many other plant-eaters, this side-street is an important part of the digestive apparatus, and perhaps the appendix at the end of it is also of use in such animals.

CHAPTER XV

THE GREEN PLANT

PLANTS MUST FEED – THE MOUSE AND THE DAISY – SUNSHINE IS NECESSARY IF THE PLANT IS TO MAKE FOOD TO FEED ON – THE PLANT CAN USE THE ANIMAL'S WASTE GAS – WHAT THE ROOTS DO – SUGAR AND STARCH – A STARCH-PRINT – THE PLANT GETS MORE FROM THE SOIL THAN JUST WATER – IF THERE WERE NO PLANTS, THERE WOULD SOON BE NO ANIMALS

PLANTS need food, and for just the same reasons that animals do. Plants do not move about, but they are living beings; and so, like the animals, they need fuel for the work of life, and stuff to mend themselves with, and stuff to grow with.



Drawn by Marie Solari

A bit of the skin of a leaf to show the slits for letting in air, drawn very large.

From James' *Introduction to Plant Physiology* (Clarendon Press, Oxford)

It is ever so much more difficult, I know, to believe that a daisy or an oak tree is feeding than to believe that a mouse is feeding, or an elephant. You can see the mouse picking up the bit of cheese in its neat little fore-paws and nibbling scraps off it with its teeth and swallowing them. And you can see the elephant take a tuft of hay with its trunk and stuff the hay into its great, pink mouth. But however close you look, and however long you watch, you will never see a daisy feeding, nor an oak tree having its breakfast. For though the plant feeds, it does not *eat*.

The next thing to realise is that the plant needs the same kinds of food-stuffs as the animal needs. The same very simple things are needed by all protoplasm, whether it is the protoplasm of a man, or the protoplasm of a mouse, or the protoplasm of a daisy. In Chapter XIII I told you that these things are carbon, hydrogen, oxygen, nitrogen and a little sulphur: whatever else is in the food, these chemical elements must somehow be there. An animal can get these things with every meal it swallows. But the plant cannot swallow food, for it has no mouth or stomach or intestines to deal with the lumps of food or the gulps of water. The animal gets its carbon, hydrogen, oxygen and the rest by swallowing and digesting food-stuffs which are already 'composed' things – carbohydrate, fat and protein. But the plant actually first makes its own food-stuffs, and then it feeds on what it has made. The only living thing in the world that can make food-stuffs in its body is the green plant.

The next question is, where does the plant get these simpler things – carbon, hydrogen, oxygen and nitrogen – for making food-stuffs with?

In Chapter XI, when we were considering breathing, I mentioned the small holes in the plant's leaves through which air can pass. On p. 91 is a bit of the skin of a leaf, magnified a great deal, and you can see these slit-like holes here and there all over it. Through these holes the plant gets air for breathing.

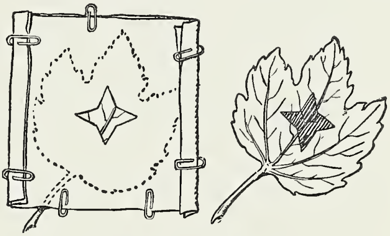
But the air that passes in through the holes into the plant is used for more than breathing. From what I have said already, you realise that air is not just nitrogen and oxygen: there is also in it a little of the gas called carbon dioxide. This gas, with water, is given off as waste by all living things when they breathe. Wherever animals and plants are living, there is some carbon dioxide in the air. And this waste gas, so useless to the animal, is absolutely necessary to the plant for food-making.

The plant first sets to work to make sugar. Sugar is one of the carbohydrates; and, as I explained on p. 78, carbohydrates consist of three things – carbon, hydrogen and oxygen. Somehow the plant must get hold of these ingredients, before it can begin. Carbon dioxide is made of two of them – carbon and oxygen; and the plant can get that from the air. Water is made of two of them – hydrogen and oxygen; and the plant can get that from the soil.

Now, if the sun is shining, the green parts of the plant have the extraordinary power of seizing carbon dioxide from the incoming air and of joining it with the water that has come up with the sap from the roots: and the result is – sugar.

If *you* took a bit of carbon – coal, for instance, or the lead of a pencil – and put it with hydrogen and oxygen, nothing would happen: you certainly couldn't hope to make sugar that way. But the green stuff of plants has this magical power. So long as the sun is shining, the green plant can make carbohydrate food-stuff for itself out of these three elements which are not, by themselves, any good for food. Some of the oxygen is not used for the sugar-making, and is set free into the air.

It is very important to notice that bit about the sunlight. Because, when darkness comes, the green plant's magic will not work any more. If you keep a growing plant in the darkness, it will die of starvation because it can no longer make food-stuff with its leaves. And at night, when the sun has set, the plant is obliged to rest from food-making. (That is why it is easier to make breathing experiments with plants when they are in the dark. Plants are really breathing all the time, day and night, in their own slow way. But in the daytime they are using up so much carbon dioxide in food-making that it is difficult to find the carbon dioxide that is coming from their bodies as waste: and, as they set some oxygen free every time they manufacture sugar, they actually make the air round them purer and purer while they work. When darkness comes and the plants stop sugar-making, the only gas that comes off is the carbon dioxide from their own breathing; and that can then be measured, if you know how to do the experiment.)



Making a starch print.

From Phillips and Cox's *A First Book of Biology* (University of London Press, Ltd.)

Having made a food-stuff, sugar, the plant proceeds to feed on it. Sugar dissolves very well in the sap and is carried round through the plant to all its parts that need an energy-giving food. You see, only the leaves and other green parts can make sugar; the deeper, inside parts of the plant are not green, and so they depend for their sugar supply on what the leaves prepare for them. But the green parts work so hard on a sunny day that they make much more sugar than is needed at the moment, so they put that into storage. The most convenient way to do this is to turn the extra sugar into another form of carbohydrate, starch, which, unlike sugar, won't dissolve in the sap.

At the end of a bright sunny day, a plant's leaves are crammed with starch. Starch turns dark blue when you put iodine on it, and there are many simple experiments you can do to show its presence in a plant. I shall give you just one. By it you can convince yourself that starch is formed in all the parts of the green leaf that have been in the sunlight, but does *not* form in the parts that are kept in the dark. The experiment is called 'making a starch print.'

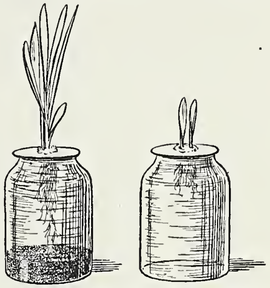
Cut a hole in a strip of black paper. Then on a sunny morning fasten the strip (by means of paper clips) across a leaf of a growing plant, and let it stand in the sunlight all day. Pick the leaf in the evening and dip it into boiling water for a few minutes. Then soak it in methylated spirit for half-an-hour until all the green colour has gone. Now paint the leaf with tincture of iodine. The part that was covered by the paper remains pale; but the part that was exposed to the sunlight will have turned dark blue. The blue colour shows where the starch has been stored in the leaf during the day; the pale parts got no sunshine because you screened them with the paper, and so they could make no carbohydrate. The experiment shows two things, (1) that starch is formed in the green leaf, and (2) that it is formed only when the sun has a chance to shine on it. The picture on p. 93 shows a simple sort of starch print. You can get more amusing ones if you first make a stencil of the paper by cutting your initials or some pattern out of it: at the end of the experiment the cut-out parts will show up blue.

Next time you look at a tree in full leaf, I want you to notice how the leaves are arranged on the branches so that they overlap one another as little as possible. They keep out of one another's light as much as they can, so that all may get a full share of the sun's rays and make as much starch as possible for the plant.

Starch, then, is a food-store of carbohydrate. Some of it is stored in the leaves, but some is stored in other parts of the plant. Once the store is made, the plant can draw on it for the food it wants. It can't use starch straight away; it has first to turn it back again into sugar, because sugar is the carbohydrate that will mix well with the sap and go streaming about all through the branches and twigs to the other parts that have to be fed. If you test your leaf for starch first thing in the morning instead of in the evening, you will find scarcely any blue colour. The starch that was stored in the leaf the day before has been turned back into sugar and has been sent away as food.

I wonder if you notice that I seem to have left something out ? I have said not a word all this time about nitrogen, although in the beginning I said that the plant's protoplasm must have nitrogen as well as carbon, oxygen and hydrogen. Where does the plant get its nitrogen ? It would be natural to suppose that it gets nitrogen from the air, because so much of the air is made of nitrogen, and we know that air is going in through the holes of the plant's leaves. But, as a matter of fact, the green plant does *not* get its nitrogen that way.

It gets its nitrogen from the soil in which it grows. In the soil there is plenty of stuff containing nitrogen, in the form of salts called nitrates, and this stuff gets into the roots with the water and is carried with the sap all about the plant's inside. Along with the nitrates also come in the other salts, containing iron and magnesium and so forth, that are very necessary for the plant as well as for us and for the animals.



Drawn by L. R. Brightwell

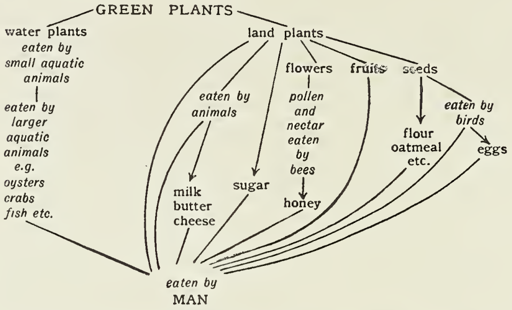
Seedlings growing in water mixed with soil, and in water only.

From Andrade and Huxley's *Science and Life* (Basil Blackwell)

You know that if you pull a plant up by its roots, and wash them well, and stand the plant in quite pure water, it won't flourish long. That is because the water hasn't the chemicals with nitrogen and the other necessary things. But if you mix plenty of soil with the water, you will find the plant gets along all right and grows bigger.

Now the nitrogen in the soil mostly comes from the decaying of dead plants and the bodies of dead animals, and from the waste – urine and the undigested remains of the food – thrown out from animals' bodies. The waste from the bodies of animals enriches the soil and so helps to feed the plant.

What I want to make especially clear in this chapter is that, before it can feed really, a plant must first make its food-stuffs, its carbohydrates, fats and proteins, out of gas and water and minerals; and *no animal can* *do this.* As I said in Chapter II, and again in Chapter XIII, the green plants are the only living things that have this power. And this means that since all the food-stuffs are made by plants, animals are entirely dependent on green plants for food.



Food relationships existing between green plants, animals and man.

From Wyeth's *Elementary General Biology* (G. Bell & Sons, Ltd.)

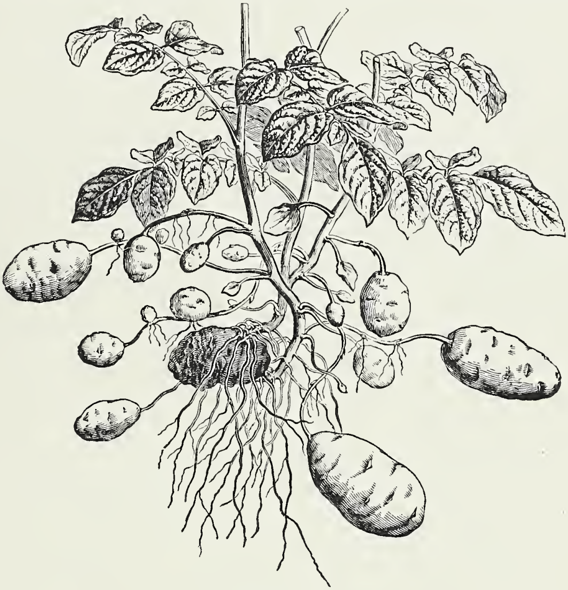
If for some reason the plants on this earth were all to die, then very soon all the animals would die too. Were you thinking that the animals could get along by eating one another? It is true, of course, that the lions could go on eating the zebras, and the wolves could go on eating the sheep, and the owls the field-mice, and the spiders the flies. But think a minute! What would the zebras and the sheep and the field-mice and the flies live on if there were no plants? All these animals that get eaten are vegetarians: they live on grass and other plants. So, you see, if the green plants all died, the vegetarians would die of starvation: and so in the end there would be no prey for the flesh-eaters. And we should die too. Plants are all-important for the animal world.

CHAPTER XVI

FOOD STORES IN PLANTS

A STORE-CUPBOARD FOR THE WINTER – AND FOR STARTING GROWTH IN SPRING – THE POTATO IS NOT A ROOT – BUT THE CARROT IS – THE POTATO'S EYES EXPLAINED – THE ONION AND THE HYACINTH BULB – THE BEAN AND ITS FOOD-STORES – THE SEEDLING

WHEN the plant has made the food-stuff, some of it is used at once. But more is made than is needed at the moment, so some is put in store, and then gradually used up later on as it is required.



Potato plant.

From Groom's *Elementary Botany* (G. Bell & Sons, Ltd.).

During the bright, sunny weather that comes in summer when the days are long, the green parts of a plant can make a tremendous amount of food: some of that is needed to keep the plant alive and in good repair, a lot is used for growing, but still there is plenty left over. So, in addition to the little temporary stores in the leaves, the plant has special, larger store-cupboards in which it can put away the extra stuff for a time when food may be difficult to get. That time comes with the winter. The days get shorter and shorter, so there is less and less light in the twenty-four hours; the sun shines less strongly; and there is usually more cloud in the sky. The temperature falls: the air and the soil around the plant get colder. All this makes it harder and harder for the plant to work at food-making. And when winter has almost come, the plant gives it up as a bad job. If it is an herbaceous plant, it 'dies down,' as we say: all the part above ground withers away, and the gardener cuts it off. If the plant is a tree or a bush, it usually sheds its leaves instead.

It is not really dead: it is just resting; but even when a living being is at rest, it needs some food to keep it alive. So this is when the plant draws a bit on what it laid by. Then, when the spring comes, the plant wakes up and begins to sprout. The herbaceous plants put up new shoots; the trees and bushes grow a new set of green leaves. Even though there is not a great deal of sunshine in these early months, the plant can begin to grow quite quickly, because it gets a good supply from the store-cupboard that it filled the summer before.

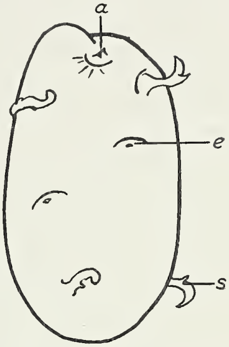
By the time summer arrives, the plant is in splendid form and able to make the most of the long hours of sunshine and of warmth.

Now, different plants have different places for keeping these stores. The great trees store food in their stems and branches. The smaller plants may do that, too. But the plants that die down in winter have no stems and branches above ground, in which store-cupboards can be arranged. Such plants have stores below ground, as a rule.

A very good example of a plant with an underground store of food is the potato. You know the potato as one buys it in the greengrocer's shop, when it has been cut off from the plant. But if you have ever seen men digging for potatoes, you know that they usually wait to do this until the potato plant with its big dark-green leaves and its gay purple or white flowers has withered. In the autumn the men in the fields root up the withered potato plant with a sort of fork; and hanging to the underground part are the brownish potato vegetables, some little and some big. The first picture in this chapter shows a potato plant that has been dug up before withering, and you can see the potatoes, one at the end of each of the branch things that are growing from the main stem.

I said 'branch' there, because it is not correct to say that the potato is a 'root.' The potato vegetable is really just the end of a shoot, swollen out with stored food. It happens to be below ground; but that doesn't make a root of it. You can see the real roots in that picture on p. 97, in the middle, below the place where the potato shoots are growing out from the stem.

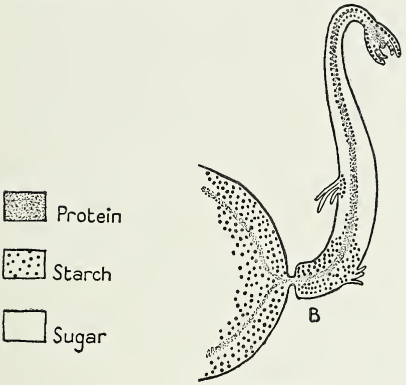
The outside of a potato is covered with a brownish, corky skin, the part people usually peel off before cooking. At one end is a little mark which shows where the potato was fastened to the plant. Here and there on the surface are smaller, blackish marks; these are called the 'eyes' of the potato. Of course, they are not really eyes at all: no plant has eyes, and anyway, what would be the use of eyes underground? But they look rather like the drawing of an eye with an eyebrow above it.



Potato with developing shoots. *a*, scar of attachment; *e*, eye; *s*, shoot.

Modified from Poulton's *Teaching of Biology*. (Methuen & Co., Ltd.)

If you slice the potato open with a knife, it looks the same all through – a sort of creamy-yellow, firm stuff. If you put iodine on the cut surface the creamy-yellow colour changes to blackish-blue: which means that the inside of the potato is mainly made of starch. It is a large store-house of starch, and the plant would use that for growing with when it sprouted again in the spring. But even a potato plant cannot live on starch alone. It must have protein, for instance. And there is some protein in the potato. In the picture alongside is a bit of sliced potato with its new sprout, and the starch is shown as coarse dots: but there is also a part, not very deep below the skin, marked with fine dots, and that is where the protein is stored. I'm sure you've heard it said that potatoes cooked in their jackets are more nourishing than those that have been peeled first: now you see why. In peeling, one is pretty certain to cut away the protein store and leave the carbohydrate only.



Modified after de Vries

Bit of sprouting potato cut longways to show distribution of food-stores.

From James' *Introduction to Plant Physiology* (Clarendon Press, Oxford)

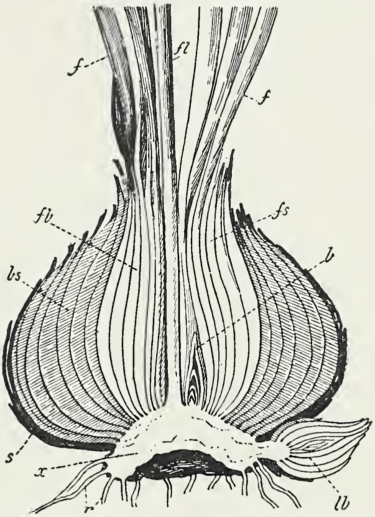
Now let us come back to the 'eyes.' If you put a potato in the dark where it is warm and moist, you will find that from each of the so-called eyes a tiny sprout will grow, for the eye is really a very small bud: and roots will begin to grow down from below this little new shoot. It is not necessary to put the potato in the ground for this to happen; perhaps you have sometimes found potatoes sending out pale shoots where they lay in a heap in some dark outhouse. But to get your potato-growing beyond that first stage, the potato must be properly planted. Then some of the shoots will grow up above the surface and turn a good bright green and send out big green leaves, and in the summer there will be flowers, purple or white. All the first part of the growing is done at the expense of the store in the potato; and if you dug the thing up after the plant was well formed, you would find the remains of the old vegetable shrivelled and almost empty, while already new, young, tiny potatoes were forming at the ends of the underground shoots. Supposing you didn't dig the plant up, these new potatoes would swell and swell as the summer went on, filling up with the new food-store the plant makes for itself in the sunshine by the help of its leaves and its roots.

If, when you were planting, you wanted to make your first potato go as far as possible, you could cut it into bits, each with one eye, and plant each of these bits separately: each eye or bud would have its own share of the food-store, and each would sprout by itself just as cuttings of a geranium do. If there were six eyes on your potato, you could get six potato plants that way.

Vegetables like carrots and turnips are also food-stores of the plants they belong to. Only here the store really is in the root. The root of the turnip is swollen out with an enormous store, mainly of starch. In the carrot, the store is mainly of sugar. Carrot and turnip plants last through two years. In the first year the plant grows from a seed and makes a lot of green leaves, and these prepare the food-store which is kept underground in the root. Then in the second year, if it is not dug up by the gardener, the plant will grow mainly at the expense of the food-store and will form its flowers and, in the flowers, its seeds.

The underground parts of the leaves are sometimes used as the food-store. A good example of this is the common vegetable we call the onion. The onion is really an underground shoot – some of the leaves of which are crammed with food. I don't advise you to cut up onions to see what they look like inside, for they are so hard on the nose and eyes. But it is quite convenient to cut up a hyacinth bulb or a daffodil bulb, and these are made on the same plan as an onion really.

The picture on this page shows a hyacinth bulb cut longways. At the bottom of it is a sort of pad, marked *x*: that is really the short stem of the shoot, and at the top of that is a bud, which next year will become the flower-stalk and the green leaves. All around the bud and growing out of the short stem, are the bases of the leaves which were green during the summer, and which are now filled with a food-store of sugar. Further out still, are thin, brownish scales; these are the shrivelled bases of the leaves that acted as food-store for *last* year's flower and greenery. They are dying now, but they can still be of some use in protecting the softer parts inside. You can see the little roots, marked *r*, growing into the soil from the bottom of the bulb. This year's big green leaves and the main stem and, later on, the flower, will all be built up from the food-store in the bulb leaves, along with what comes in from the soil by the roots. A great many of the spring flowers grow from bulbs: snowdrops, for instance, and daffodils, and then the bluebells. And you can see now how it is that a snowdrop can make such a good show at a very unfavourable time of year and before it can have a chance to do much food-making on its own.



Hyacinth bulb cut open longways. *b*, bud; *f*, foliage leaves; *fb* and *bs*, leaf-bases with food-store; *fl*, stalk of flower; *s*, scale; *x*, flattened stem of bulb; *r*, root.

From Groom's *Elementary Botany* (G. Bell & Sons, Ltd.)

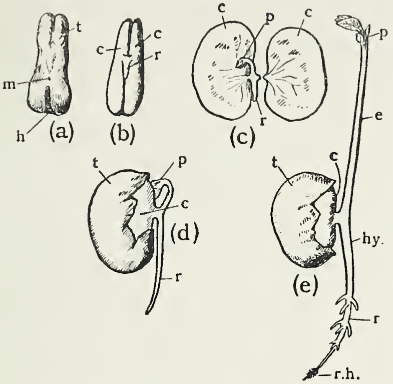
Even if they look very untidy in the garden, it is best to let the leaves of all such bulb plants grow on and on long after the flowers have withered: for that gives a chance for a new food supply to be stored in their underground parts for next year. If you cut the leaves off too soon, new bulbs will not be formed, for there will be nothing above ground to do the food-making.

The plants I have just been describing go on for many years; others, like the carrot and the turnip, never go on for more than two. And there are a great many that live for one year only. But whether they live for one year or for many, all these plants have another place still where they store food for the future. This store they *all* have is in what we call the 'seed.' The seeds of a plant are what you may think of as its eggs; and inside each seed is tucked away the very small beginnings of a new plant, together with a food-store. The seeds are cast off from the parent plant, where they have been formed in the flowers: but before they are set free, they are given their food-store, so that there shall be plenty of nourishment all ready for the new young plant that will grow from them when the time comes.

As an example of a seed food-store I shall take the bean. If you look at a bean's outside, you can see that the thing is wrapped in a tough coat which protects the parts inside. This seed-coat is porous for water, and it also lets in air. After you have soaked a bean in water for some time, it looks larger. It hasn't really grown: it has just swelled with the water that got in through the seed-coat. If you squeeze a soaked bean, this water will come out again through a small hole on one of the narrow edges: the hole is marked 'm' in the picture 'a', where a bean is shown, narrow side on.

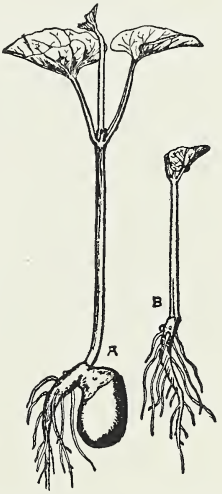
Just below that hole, m, do you see a black mark, h? In the real bean, this is a greyish scar, and it is the place where the seed was fixed inside the pod. And just above m is a little pointed thing. That is the tiny root of the young plant inside the seed. If a bean has been well soaked, it is not difficult to peel the seed-coat off: then it looks like the next picture, b. Again you see the tiny root, marked r, and right and left of it there lie what are called the seed-leaves: they are marked c. If you separate the seed-leaves gently from one another and spread them out, as in the third picture, you see between them the little root, and above it, tucked well in, the baby shoot of the new plant, marked p. Now, in the bean-seed it is the seed-leaves that contain the food-store. They are pale, thick, solid things, crammed with starch and protein. The starch will turn blue-black if you put iodine on the cut surface of a seed-leaf.

If a bean-seed is to sprout, there are three things you must remember. (1) There must be enough water. The soil, or whatever you plant it in, must be sufficiently moist. (2) There must be oxygen. Seeds, like all plants, breathe. Therefore the soil around must not be packed so tightly that air cannot get in. (3) There must be warmth. The growing will not begin if the seed is so chilly that it can't digest its food and make use of it. But if your bean-seed is moist enough and warm enough and getting some oxygen, the little plant begins to increase in size and the seed-leaves begin to lose their contents. The water from the soil gets in through the seed-coat, and the seed-leaves swell and burst the coat along one side (the burst seed-coat is marked t in the fourth of those pictures). The little plant is now digesting the food-stores in its two seed-leaves, and it grows at the expense of that store. The root pushes its way out and grows down into the earth: and the shoot, with its head bent like a crook, pushes its way upwards through the soil towards the light. In the picture marked e it has grown a good deal. The first root has small side-roots growing from it; the shoot has got fairly long and has straightened itself, and it is beginning to unfold its own first green foliage leaves and spread them in the sun. But for some time these new upper leaves are not big enough to make much starch, and the young plant still draws on the store in the seed-leaves below ground. To show how dependent the seedling is on its food-store, two very young bean-plants are compared together on this page. The larger one has not been interfered with: it has grown tall and strong and has good leaves of its own already. The other one has had its seed-leaves nipped off soon after it began to sprout



Sprouting of Broad Bean. (a) Bean from outside; (b) the same, with seed-coat removed; (c) the seed-leaves separated to show the young plant inside; (d) the sprouting has begun; (e) an older seedling. h stands for the place where the bean was fixed in the pod; m for a small hole; c for the seed-leaves with their food-store; r for the young root; p and e for the young stem with its first leaves.

From Wyeth's *Elementary General Biology* (G. Bell & Sons, Ltd.)



Seedlings of Runner Bean. (A) Normal seedling; (B) seedling of same age, but dwarfed because the seed-leaves have been nipped off soon after it began to sprout.

From Fritsch and Salisbury's *Botany for Students of Medicine and Pharmacy* (G. Bell & Sons, Ltd.)

so that it had no store of food to help it; and you can see what a miserable little stunted thing it is compared with its brother.

By the time the seedling has grown as tall as in the picture marked A, the underground store has almost vanished: but that doesn't matter now, because the plant has enough leaves to make its own foodstuffs, with the help of the well-grown roots, which are getting water and salts for it from the soil. The seed-leaves shrivel as the need for them goes. From now on, the bean-plant will grow very fast in the sunshine and make lots more leaves, and then flowers, and lastly the fruits that we call pods. Inside the pods it will grow a new set of bean-seeds; and inside these bean-seeds there will be a fresh lot of baby-plants for the next spring, with their seed-leaves stored with starch and protein. The pods will burst when they are ripe, the seeds will fall out on the ground and will lie there in a state of rest until the spring comes again, when they will sprout just as the beans did that gave rise to their parent-plants the year before. So it goes on, year after year, each lot of bean-plants laying up food-stores for the generation that is to follow them when they are dead.

CHAPTER XVII

HOW ANIMALS KEEP WARM

COMFORTABLE WARMTH – HOW TO KEEP WARM ON A DESERT ISLAND – TAKING A FROG'S TEMPERATURE – THE IMPORTANCE OF SURFACE – WARM-BLOODED ANIMALS – THE BIRD'S 'NORMAL' – SWEATING AND FLUSHING – AN APPETITE FOR FAT – ANIMALS' CLOTHES – WHY A HOT DOG LOLLS OUT HIS TONGUE – WHY BIRDS SIT ON THEIR EGGS AND ON THEIR NESTLINGS

THE stuff of which all animals and plants are made must be kept comfortably warm if it is to do those things that make us call it 'living.' Protoplasm must not be allowed to get too cold, or it will die: but also it must not be allowed to get too hot, or it will die. If this earth got very much hotter than it is now, or very much colder, everything on it would die. There would be no plants and no animals any more. The living stuff, protoplasm, can do its work only between certain temperatures.

But the temperature of the air or water outside the living body is not the only thing to consider. Remember that living protoplasm is all the time making some heat on its own. Even a plant makes some heat in the process of living: the heat given off by sprouting bean-seeds will raise the temperature of the surrounding air quite noticeably.

After what I have said in Chapter X, you realise how this inside heat is produced in a living animal. Every time a muscle is used, for instance, food is being burnt to give the necessary energy: but only about a quarter of that energy is used for the work done by the muscle; about three-quarters appears in the form of heat.

If it is a very cold day and you want to get warm, what do you do? You might light a fire and warm yourself by that outside heat, of course. But supposing you are on a desert island and have nothing to light a fire with. You have been cast ashore from the shipwreck and you are shivering from the cold of the water. Of course you would know what to do to get warm. You would run about and work your muscles hard, so that a lot of inside heat is produced: and if there were some fat or butter among the food-stuffs that had been saved from the wreck, you would do well to take a good deal of this on your bread, for fat is the fuel that gives heat most quickly when it is burnt in the body. As you run up and down the shore of the desert island and munch your bread-and-butter, gradually your body begins to glow with the heat that is coming from inside you. The air around you is still cold, but you yourself are getting nice and warm. Your blood is carrying to every part of you the heat made in your muscles, so that all your protoplasm works well again.

And if by good fortune a thick, tweed coat has been saved from the wreck, you will put that on now. The coat will prevent the cold air from reaching your body; but it will do something more for you than that: it will prevent the heat your body has made from escaping away into the air. The coat keeps in a layer of warm air next to your skin; and now you feel nice and cosy.

Supposing, now, the sun comes out hot and strong. You begin to feel uncomfortably warm, even though sitting still. You throw off your coat, but still you feel too hot. The outside air is warming your body: which partly accounts for the heat you now feel. But don't forget that, though you have moved into the shade and are sitting quiet, your body is still making its own heat. True, it is making ever so much less heat than when you were running about and using your muscles hard, but it is making *some* heat, for all that. Your heart is beating, your chest is heaving up and down as your lungs fill and empty, your stomach and intestines are pushing about and digesting the bread-and-butter you have just swallowed. To do any one of these things fuel must be burnt and heat is given off.

If you want to get cool again, you will probably get into the sea, so that some of the extra heat is quickly lost in the cold of the water. And if you still feel hot when you come out, you won't dry the water off your skin; you will lie down and let it evaporate. When water evaporates, it changes from being a fluid into being a gas, and when that happens, some heat is always used up. Now you feel nice and cool for a time.

If you put your hand on the pebbles beside you on the beach, you will find that they too have heated up in the sun; as midday approaches they may get so hot that you can scarcely touch them. But as the sun goes down, the stones cool again; and if it is a cold night, they will be quite cold to the touch by morning. The stones, since they are not alive, cannot produce inside heat of their own, and they change their temperature with the temperature of the air around them.

Now about animals. . . . We find that most animals change their temperature with the temperature outside them in the air or the water in which they live. I'll give you an example of what I mean. Supposing you took a frog's temperature on a warm, sunny day, you would find that the quicksilver in the thermometer you put into its mouth would go just about as high as the quicksilver in the thermometer hanging up in the room. A comfortable temperature for a room is somewhere about sixty to sixty-five degrees. Well, a frog in that room would have about the same temperature inside its body – about sixty to sixty-five degrees. But if you keep that frog out in the garden on a very cold day when there is frost on the ground, and take its temperature again, you will find that the quicksilver in the thermometer in its mouth does not rise much above thirty-two degrees, which is freezing-point.

And if you *could* take a fly's temperature, you'd find the same thing. The fly would have a high temperature on a hot day, and a low temperature on a cold day. . . . It would be the same with a fish. When the water in the pond is warm, the fish's temperature goes up a bit: when the water is cold, the inside of the fish's body also gets colder. And it is the same with the bodies of lizards and snakes and newts, and the same with the bodies of the snails and earthworms and all the small, invertebrate animals. We say that these animals are 'cold-blooded.' That is not a very good word, though. Because, as I was explaining, though their blood is cold in cold weather, it may actually be pretty hot in hot weather. I would prefer to call them 'animals with a changeable temperature.'

While you have been reading these last two paragraphs, I expect you have been saying to yourself that surely I must be making a mistake. For up till now I have been insisting that the living, active creature is continually making heat inside itself, and what could be more active than a fly or than a lizard ? Now it is perfectly true that these animals do make some heat all the time, and quite a lot when they are running or flying about: but – this is the thing to notice – these animals lose their heat almost as fast as they make it; it simply goes off from the surface of their bodies into the air or the water. Note that about the *surface*, too. Most of the very active land animals with changeable temperatures are small animals; and since a small thing has a very much greater surface in proportion to its bulk than a large thing has, the small cold-blooded creature, however active, will lose heat very quickly.

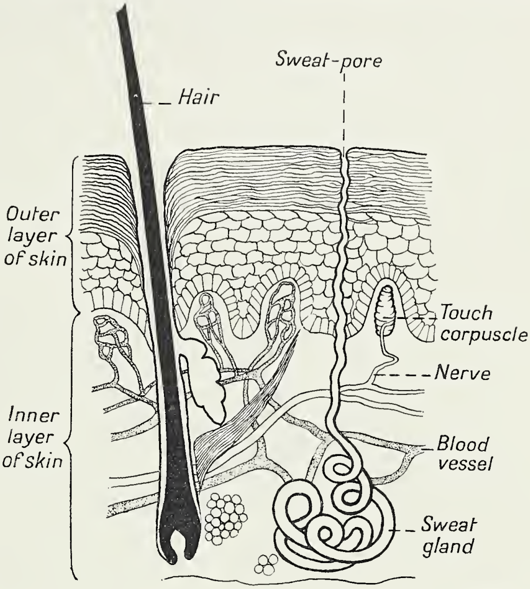
There are two sorts of animals that are not cold-blooded. These are the birds and the hairy animals, the mammals: and among the hairy animals there is Man. The birds and the mammals are what is known as 'warm-blooded': or, if instead of 'cold-blooded' you used the expression 'with changeable temperature,' then instead of 'warm-blooded' I would like to use the expression 'with even, or constant, temperature.'

To explain what I mean by having a constant temperature, let us go back to that child on the desert island. We'll suppose that the ship's doctor was among the people saved from the wreck, and in his pocket he has his thermometer all safe. Now, just for fun, when the child has been running about on the shore and comes back to camp and throws himself down saying, 'Oh, I am so gloriously hot now!' the doctor takes his temperature. After a minute or two, he takes the thermometer out of the child's mouth, and looks at it: the quicksilver has risen to four points above ninety-eight. Then the child goes into the sea to cool down, and lies about on the shore all wet, to cool himself still further by the water's evaporation from his skin. Again the doctor takes the child's temperature. The child is now feeling almost too chilly, but, extraordinary though it seems, the quicksilver in the glass again rises to exactly what it was the first time – ninety-eight point four. The child's body temperature remains the same, whatever the temperature of the surrounding air or water may be, and whether the child feels hot or cold. (I am supposing, of course, that the child is healthy and well. If he got a sore throat or ate something poisonous, his temperature might go up; then the doctor would say he was feverish and put him to bed for a few days till he was well again and had a normal temperature whatever the weather.)

That is what is meant by being 'warm-blooded.' Your body has the extraordinary power of regulating its temperature so that it remains the same however hot or cold the day and however much heat you are making. And the particular temperature it stays at is the very best temperature for your protoplasm to do its work. All the hairy animals have constant temperatures, however small their bodies. Not necessarily a normal temperature of ninety-eight point four, as with us; but a temperature that is just the right one for protoplasm of cat or dog or rabbit or horse to work in. Birds have a very high normal temperature; for a bird to have a temperature of a hundred and five is quite usual. If you or I had a temperature of a hundred and five, we should be most dangerously ill; but a hundred and five is 'normal' for a bird. The bird couldn't get on at all with such a low temperature as ninety-eight point four.

How is it that the body of the even-temperatured animal is able to keep things just right, so that things inside never get too hot or too cold? I cannot give you the whole answer to that question, but I can answer it partly.

First, about getting cool. All the time, your body is losing water through the millions of tiny holes, or pores, in your skin; and as long as the air is not too damp, this moisture from your skin evaporates so quickly that you are not aware of it. In evaporation, as the water changes into gas, heat is used up and lost from the body, and so the body is made cooler. The more active you become, the more water is poured out from the skin; and so much may come out that it runs in drops down your skin. Then you say that you are sweating. Sweat is very nearly pure water; but there is some salty stuff in it, as you know by the taste if you lick your upper lip after you have got very hot. (One of the organs that make the sweat is shown in the diagram.)



Drawn by B. Phillipson

Diagram of a vertical slice through the skin of a mammal. (Note especially the sweat-gland and the branching blood-vessels. Also a hair.)

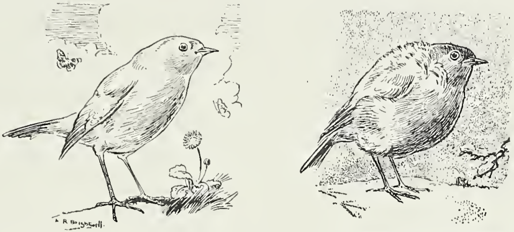
Then, on a warm day, or when you have been running hard or have somehow made a great deal of heat, your skin gets redder: you flush. The redness comes from the blood under the skin shining through. When the body is in danger of getting overheated, the little blood-vessels of the skin widen, so that more of the hot blood comes near the surface and heat escapes quickly. If you hold a cool hand near the face of a hot, flushed person, you can feel the warmth coming from his body, just as you might feel it coming from a radiator.

So much for the way your body loses the extra heat it has made, and thus cools itself. How does it preserve the heat in cold weather ? The skin goes paler, for the little blood-vessels of the skin become narrower, so that less blood comes near to the surface and less heat passes out. Sweating is reduced to a minimum. The appetite for fats and other heat-giving foods increases with the cold. (Eskimos in the Arctic live very largely on seals' fat or 'blubber,' as you know.) And we put on more clothes, or thicker clothes, to hold in the heat we have made.

Now, what about the other warm-blooded animals ? How do they compare with us when it comes to keeping their bodies warm ? One of the most obvious differences between them and us is that they haven't clothes that they take off and put on every day. But they do have a *kind* of clothes: clothes of fur or of feathers, which they wear all the time. The air under the feathers or under the fur gets warmed up by the animal's blood, and, entrapped and entangled in the feathers and hairs, it doesn't give up the heat at all easily. It's like wearing a homespun tweed suit, very light and warm. If we compare the coarser hairs and the bigger feathers to a tweed suit, then we might go on to speak of the animal's underclothes; for lots of animals have fine, short, fluffy hairs under the coarse ones, or, if they are birds, exquisite down feathers next to the skin.

When winter is coming on, you find that most of the hairy animals grow a thicker coat to get ready for the cold. You can see that easily in the cart-horses in the street. They look satiny in summer, but in winter they look velvety. And when the summer is coming, the animal usually moults its winter coat: you must have noticed how your dog's hairs come out in the spring.

A thick, close coat of feathers is extremely important for a bird. It is true that the bird's muscles make a great amount of heat, but while flying fast and far high up in the air, the bird meets with very cold currents sometimes, even in summer; its feather coat then helps it to retain enough heat to keep its temperature up to the high bird normal. When I was explaining about flight in Chapter VII, I drew your attention to the way the feathers are arranged on the bird's body, with their tips directed backwards. At the time, I pointed out that this helps to keep the shape smoothly stream-lined in flight; but you can see now that there is another advantage. If the feathers grew out in all directions, the cold air would easily blow in under them and blow away the warm wrapping of air.[1] Have you ever noticed that, when sea-gulls are standing in a field, they always face the wind ? If they stood with their backs to the wind, the cold air would blow in under their body-feathers and chill them. And you should also notice that in cold weather a bird fluffs its feathers out, so that it looks plumper than it does in warm weather. That picture of the robin redbreast shows what I mean. The bird is doing that, so that the warm air layer next the skin is made as thick as possible. You'll find yourself that if you wear rather loose-fitting clothes, you'll keep much cosier than if they fit close against your skin.



Drawn by L. R. Brightwell

A robin redbreast on a warm day and on a cold day.

From Andrade and Huxley's *Science and Life* (Basil Blackwell)

So much for the way warm-blooded animals keep the heat in. How do they cool their bodies when they make a lot of heat with exercise or when the air round them is very hot in summer ? Many of the hairy animals perspire, just as we do. I'm sure you have often seen a horse's coat all streaked with sweat when it has been running hard or dragging a heavy load up a hill. If the day is at all chilly, the horse's master then puts a small blanket on the horse's steaming back, so that the sweat shall not evaporate too fast and chill the creature while it is kept standing.

Dogs, curiously enough, have few sweat glands. So what a dog does to cool himself is to open his mouth and loll his wet tongue out and pant very fast. The air rushing quickly out of his hot lungs into his open mouth is cooled, and every lungful and mouthful of air carries off a good deal of heat to the outside. The water in the mouth evaporates, too, and that helps the cooling.

Dogs are extremely clever animals. You must often have noticed how they seem to think things out for themselves and do things their masters never taught them. An example of that comes to my mind now in connection with getting cool. A dog I knew was one of those big terriers called Kerry Blues, with a thick, silky, blue-grey coat. To his master's surprise, in very hot weather Paddy would go and lie for choice in the very hottest place he could find, right in the sun – instead of seeking the shade as you would have expected. Then the man watched and presently he saw what was happening. The dog would go and soak himself all over in a pond until his woolly coat was dripping wet, and then he went and lay in the hot sun, so that the water evaporated very quickly from all over him; and that cooled him down beautifully. As soon as he was dry and beginning to feel the heat again, back he went to the pond for another supply of water to evaporate and cool himself with. It was an excellent plan. Perhaps at a picnic you have seen them keep the lemonade cool by wrapping the bottle in wet flannel and putting it in the sun! It is the same idea.

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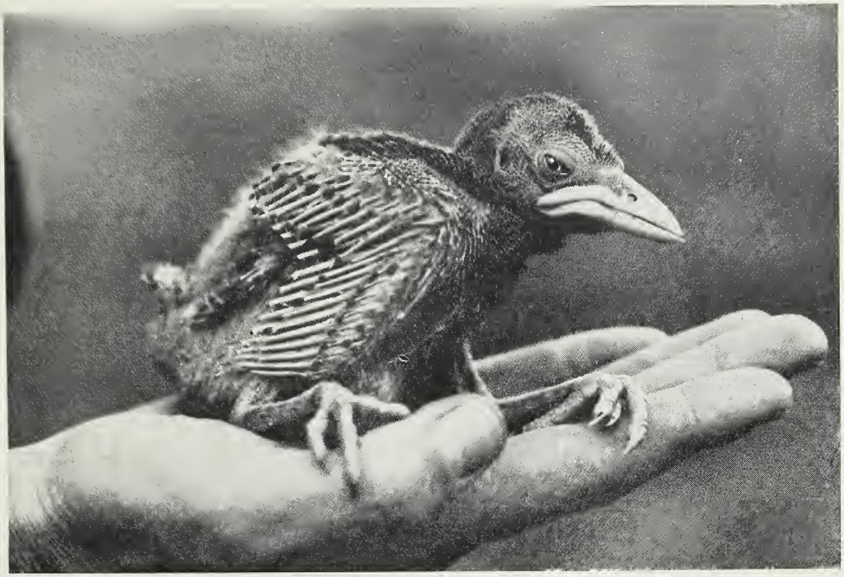
[1] Yet another use of feathers is to act as a waterproof coat for the bird The surface of a feather is slightly oily, so that it throws off water.

One would think that those active animals, the birds, might very easily get over-heated in warm weather; yet their body-temperature, though the 'normal' is high, remains constant. The bird does not loll its tongue out like the dog; and if you examine its skin, you'll find that no sweat comes from it: the bird's skin is always dry. So it is rather a mystery how the bird keeps its temperature down. Probably, in spite of the feather coat, a lot of heat is lost in flying through the cold upper air; and then it seems likely that moisture evaporates from those peculiar air-sacs attached to the lungs.

It is worth noticing that when the bird is newly hatched from the egg, it doesn't seem to have the power its parents have of regulating its body-temperature: and often, as you know, the helpless young bird is without any feathers to prevent heat escaping too fast from its body, and it is not strong enough to take exercise. That is one reason why the parent birds sit on the young in the nest, to give them warmth with their bodies and keep in the heat, until the young have grown their feathers, can move about, and have developed the power to keep an even body-temperature. In very hot weather, the parent birds also sit on their young, to keep the fierce heat of the sun from reaching them and sending their temperatures up too fast. Sometimes on a hot day you may see a nest of young birds with their beaks wide open and seeming to gasp for air.

The parents have gone to look for food, and the young are feeling the heat and trying to cool themselves a bit by panting air in and out of their mouths and lungs very quickly.

Even before the young hatch out, the eggs must be kept warm if the little birds inside are to live and grow. So the hen-bird sits on her eggs and warms them with her body. If she is frightened away by some thoughtless person, the eggs get cold and the young birds inside of them will die.



Photo, Rufus Mallinson

A baby jackdaw. Note that the feathers are beginning to grow.

In the next chapter I shall explain some of the great advantages of having an even temperature.

CHAPTER XVIII

WINTER SLEEP

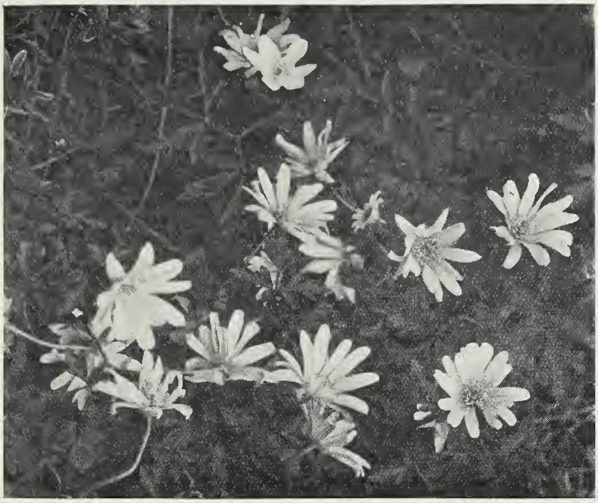
WHAT IS SLEEP ? – PLANTS ARE OBLIGED TO REST AT NIGHT – THE PLANT ECONOMISES ITS WATER-SUPPLY – WINTER IN THE PLANT WORLD – WHY A PLANT LOSES ITS LEAVES – EVERGREENS – DRAWING ON FOOD-STORES – SPRING'S AWAKENING – WINTER IS HARD ON ANIMALS – MIGRATION – LIVING ON ONE'S OWN FAT – THE ADVANTAGES OF BEING WARM-BLOODED

WHAT exactly do we mean by 'sleep' ? . . . When we talk about an animal sleeping, we mean that it stops moving about, relaxes its muscles, and rests so completely that its brain and even its heart are doing much less than usual. It rests its body all through. It stops feeding, and so its stomach gets a rest; it breathes more slowly, and so it rests its lungs; it rests its eyes by shutting out the light with its eyelids – if it has eyelids ! All the things that go on in the animal's body while it is awake, still go on, but ever so much more slowly, when it is asleep.

Plants also take some rest at night. It is more difficult to know that plants are resting, because they have no legs to stop moving or eyes to close. But when darkness comes, the plant is obliged to cease making food with its leaves, and so rests its leaves: and it doesn't take in so much water with its roots, and so its roots get some rest. And because the plant is not working so hard, it needs less oxygen, so all the business of its breathing goes even slower. Some plants give a clear sign that they are sleeping, as when they fold their petals together in the evening to protect the centre of the flower from dew and cold: and towards evening the three little leaflets of each green clover-leaf fold back along the stalk.

These movements connected with the sleep of plants have a good deal to do with preventing water escaping too quickly into the air from the surface. Water is immensely precious to the plant, and it must not be wasted.

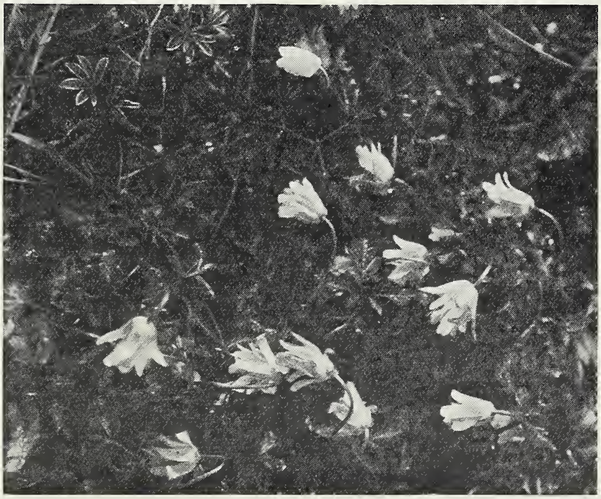
You know how, if you pick a leaf, it fades very soon, it gets quite flabby, especially if it is in a warm room. All over the leaf are the tiny holes through which air enters for breathing and for food-making; and also



Photo, Prof. E. J. Salisbury

Anemones in sunlight.

From Salisbury's *The Living Garden* (G. Bell & Sons, Ltd.)



Photo, Prof. E. J. Salisbury

Anemones towards evening.

From Salisbury's *The Living Garden* (G. Bell & Sons, Ltd.)

through these holes water escapes. Water from inside the plant evaporates as it comes out through these holes, much in the way your sweat does when it comes out through the pores of your skin; and that helps to keep the leaf cool on a hot day, just as the evaporation of sweat cools your skin. If you smear the leaf with stuff like vaseline so that you block up the holes, it will stay stiff much longer, because the water cannot so easily escape away. It was the loss of water that made your picked leaf go flabby. And when it is growing on the plant, the leaf has the power of regulating the size of the holes, so that just enough water vapour is lost and no more.

But if the living plant kept its leaf-holes close shut, it couldn't get air to breathe and carbon dioxide to make into food. So they have to be more or less open. Yet, when the leaves grow on the living plant, they don't go flabby. For the water the plant is losing through its leaf-holes is all the time being replaced by what is coming in through its roots from the soil. The loss of water from the surface encourages, so to speak, a steady flow into the plant from below, and a slow, constant current is kept going. You can see the importance of this. The incoming water brings with it nitrates and the other things from the soil so necessary for the plant's life; and the current carries about with it all through the plant the food-stuffs when these have been made. If you deprive a plant of water, then, all its soft parts will wilt, it will be unable to make its food, and it will be unable to distribute such food as is in it already.

Now at night, when the air gets colder, this current of water through the plant goes slower. Less is evaporating from the surface, so less is drawn in to make up the loss. And by folding their leaves together, some plants reduce the exposed surface still further and economise the precious water supply they contain.

While it is true, then, that plants' lives go slower at night, and so you may say that they sleep, the time for their most complete rest comes in the winter. Nearly all the green plants that last more than one year have a sort of 'winter sleep.' One of the first things that show this sleeping time is near is that the leaves of a tree lose their green colour and get dry and crackly. They turn yellow and red and brown, and they get dry, and then they fall off. That happens in autumn. The leaves have died for lack of water. The tree has made a sort of wall of corky stuff between itself and every leaf; and this wall blocks up the passages to the leaf-stalk, so that water cannot get into the leaf from the stem. If a leaf cannot get water, it will wither and die; not only will it go flabby, but it can no longer feed.

But why should the tree get rid of its very useful leaves ? There are several reasons: but perhaps the chief one is that in winter the tree has to be more economical than usual of its water-supply. In winter, the green plant cannot get so much water from the soil as it does at other seasons; and so it daren't let too much evaporate away from its leaves. The surest way to prevent that dangerous loss is to drop the leaves off: so that is what it does.

You can readily understand that, if the soil is frozen, and so the water in the soil turned to ice, this stops the water inflow, for solid stuff won't go into the roots. That might explain why the shorter-rooted plants have to economise their water supply. But the big trees send their roots down very deep into the soil, right down to where the frost cannot reach. There may be plenty of water down there, cold though not frozen. Yet the tree cannot make full use of this supply. Why not ?

Plant protoplasm, like animal protoplasm, will not do its work quickly and well if it gets too cold. In winter, even quite deep in the soil, the temperature is too low for the protoplasm of the roots to work well in. In a way, plants are like cold-blooded animals: their temperature changes with the temperature of what is around them. So, when the soil is cold, the roots are chilled. Since the work of the roots is to take in water and dissolved salts, when they are chilled like that they can take in far less than usual, and only very slowly. You see then why it is that in winter the plant must be especially economical of the small amount of water its roots can get for it: and you see one reason why it makes haste in autumn to lose the leaves through which water can escape.

Another reason why the tree loses its leaves is that the leaves are the part in which it prepares its carbohydrate food. And I have explained that this can go on only when there is plenty of sunlight. In our dark winter, the sunshine is so feeble and the days are so short that the leaves get little chance of doing this part of their work. And they are chilled, too, like the roots: perhaps they are even frozen. So, as they are of little use and are actually for a time dangerous, it is best for the tree to get rid of them. Since it is a living thing, it can regrow its leaves when the spring comes and they are once more of use to it.

You may say, of course, that by losing its leaves, the tree is also losing its chance of getting oxygen. But a certain amount of air can get through the corky stuff of the bark and through the little porous walls the tree made between itself and its leaves; and though that is not very much, it is enough for the tree in winter, when it is living so much less intensely. By the time it has become active again, and so in need of a larger oxygen supply, it will have grown new leaves.

Thinking of trees like the holly and the pine, you may wonder how those plants get along that do *not* lose their leaves in winter and are what we call 'evergreen.' Don't they take great risks? It seems that these exceptional trees are able to get water from the soil even when the weather is very cold; and their tough, thick-skinned leaves are of a kind that don't lose water nearly so easily as do the softer leaves of trees like the oak and the beech.

It is not only the trees and the bushes that go into a winter sleep, of course. The smaller plants also rest. In plants like delphinium and potato and iris, what happens is that all the parts above ground wither and die down. Nothing shows above ground but the brown withered stems and dead leaves. But such plants are no more really dead in winter than is the oak tree. They also are resting and economising their water-supply until the warmth and sunshine come again. Many plants, of course, do really die at the approach of winter: the kinds that we call 'annuals' (poppies, for instance, and sweet-peas) live for one year only: these depend entirely on their seeds for starting a new crop of their particular kind next season. The other kinds go on and on from year to year, resting in the winter and becoming active again with the spring.

Now even though the resting plant is economising, it still must have some fuel to keep it alive. This is where the food-stores come in. The tree has stored food in its stems and branches, and slowly, slowly it draws on that and sends it about to all its parts so that they are kept alive and in repair. And when spring comes, there will still be plenty left to start the business of quickly growing new leaves and shoots. If you examine the twigs of a tree in autumn or in winter, you will find small new leaf-buds upon them already. Before ever the tree goes to sleep, it grows these little buds, and they sleep all through the winter with the rest of the tree, waiting for the time to come when the air will turn warm, the sap will begin to rise from the roots and the sun will shine long enough and strong enough to give a good working day. Then they will grow very quickly at the expense of the food circulating in the sap, and by degrees they will unfold and get to work.

Lest too much water be lost through the tree's buds, they are wrapped all winter in delicate brown, dry scales, through which water does not easily escape. Sometimes, as in the horse-chestnut, these covering scales of the bud are sticky with gum, which also acts like a sort of waterproof coating and prevents rain getting in.

The underground buds of the potato and the hyacinth are also got ready before these smaller plants enter on their winter sleep. The sudden awakening of all such plants as die down before the winter would be impossible if it were not for these special reserves that also keep them going through the time when food cannot be made and when water is hard to come by because of the cold.

Photo, British Museum (Natural History)

Horse-Chestnut buds.

When you remember how dependent animals are on plants, you can see how trying the winter season is for animal life. In winter animals suffer not only from the cold, but from shortage of food. Since the plants have gone into their winter sleep, there is great scarcity of green-stuff for the vegetarians, there are no flowers for the insects; and the flesh-eaters go short of food too if the vegetarians starve.

Many of the birds get out of the difficulty by migrating. They leave the cold country and fly away to some warmer place. At the end of the summer the swallows, for instance, collect in great companies and fly south to Africa to spend the winter there. They do not return to us until the summer is nearly come and there are abundant insects for their food. I daresay the cold of the English winter would be too much for the swallows anyway; but the food difficulty is just as serious for a creature like a swallow, which lives by chasing insects on the wing. When the cold comes, comparatively few insects are left alive, and still fewer of these cold-blooded creatures are able to fly about in the air where the swallows could catch them.

But supposing the animal cannot fly and therefore has to stay in England through the cold weather ? A few of our mammals get out of the difficulty by going into a winter sleep: for this winter sleep of animals we use the word 'hibernation.' The hedgehog and the squirrel and the field-mouse are good examples of hibernating British mammals: and then of course there is the dormouse. Another famous winter sleeper of the Continent is the bear.

I have called it 'sleep.' But it is a much deeper sleep than the animal sleeps at ordinary times, and it lasts for months instead of for hours. The creature lies utterly still, scarcely breathing, and no sound or shaking will rouse it. When we want to say that a person is sleeping very soundly, we say, 'He sleeps like a log': but the Norwegians say, 'He sleeps like a bear' ! When it is awake and active, a dormouse takes about eighty breaths of air a minute: but when it is in its winter sleep, cosily tucked up in its nest, the dormouse takes only ten to fifteen breaths a minute, and often there is quite a long pause before it breathes again. You see, like the winter-sleeping plant, it doesn't need much oxygen, because, while so inactive, it is not going to burn up a great deal of fuel. The little fuel that it uses is the fat of its own body (most hibernating animals are very thin

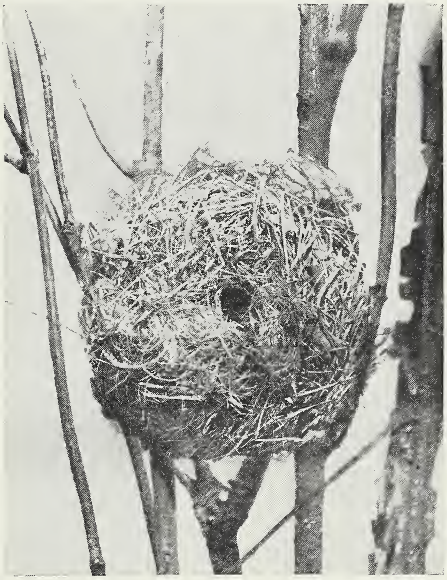
Photo, W. S. Berridge

A pair of dormice ready for their winter sleep.

when they first wake up in the spring), plus what it gets from an occasional nut when it wakes up now and then in the course of the long winter months. For the dormouse, like the squirrel and the field-mouse, lays up a store of food before it drops off to sleep. In the autumn these little animals collect nuts or grass-seeds and place them in the warm nooks to which they will retire when the days get short and cold.

The animals I have been talking about – birds and mammals – are warm-blooded: they are covered with a warm coat of feathers or of hair and they have the power to keep an even body temperature. Those birds that stay with us through the winter (robins and sparrows and many others of the common kinds) and all the mammals that do not hibernate, are able to keep active through the winter because of this power to regulate the body-temperature and keep it the same whatever the weather. There is a great advantage in being warm-blooded, as you can see. The warm-blooded creature is ever so much more independent of the weather than is the cold-blooded. It can fly or run about and keep up its warmth, and move from place to place to seek more food. So long as the warm-blooded animal is of a kind that can get *enough to eat*, it doesn't have to waste the whole winter in a state of torpor. Many of the vegetarian mammals that do not hibernate get food in winter by raiding the store-cupboards of the plants: bulbs, roots, nuts and other seeds come in very handy then.

The cold-blooded animals are at a great disadvantage by comparison. A cold-blooded animal, an animal with a changeable temperature, is active when the weather is warm, and then it can go about its business. But as soon as the weather turns cold,



Photo, Ray Palmer

Dormouse's nest. This is the nest in which the dormouse will sleep through the winter. Inside there is a store of nuts for it to eat when it wakes up.

the creature becomes of the same temperature as the air or water outside, and that temperature may be too low for its protoplasm to work well in. Its body engines, as it were, get slowed down. You must often have noticed how flies buzz about actively when it is a warm, sunny day, but walk very feebly or remain quite still for hours on end when it turns cold. And when you are in the country, you should watch the bees on the flowers or the ants running across the path on a fine day. If a thick cloud passes over the sun, or if a cold wind blows up, these bees and ants have to go slower and slower; for they are all at once chilled, literally through and through.

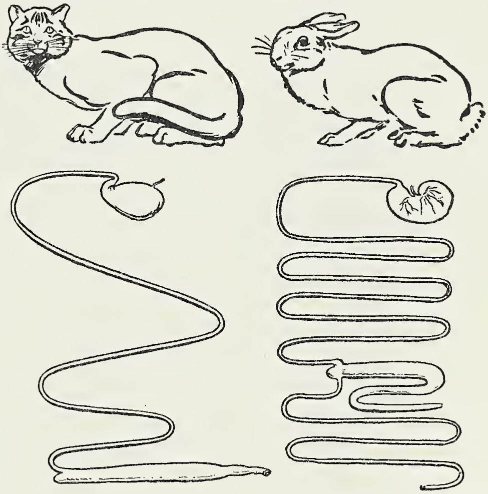
And so, when winter really comes, many of the cold-blooded animals freeze to death: their protoplasm simply won't stand the drop in temperature. But quite a number of them hibernate. They make themselves burrows in the ground, down below the level to which the frost can reach: or they take shelter in cracks of walls and tree-trunks: and in these shelters they also go into a sort of sleep that lasts for months and takes them through the cold time until the sun warms the air again. The frog is a good example of a cold-blooded hibernator. It burrows into the thick mud at the bottom of the pond when winter comes, and remains there until the spring, breathing very slowly through its skin and living on the fat it has stored in its body. Lizards and snakes in this country also hibernate; and so do earthworms and snails and the queen wasps and the queen bumblebees. When the warm weather comes, they wake up as their body temperature rises, and go on with their active lives once more as though nothing had happened. These animals with changeable temperature are compelled to hibernate by the cooling down of their bodies: whereas the warm-blooded animals that hibernate probably do so because of food-shortage rather than because they are directly affected by the cold.

CHAPTER XIX

HOW ANIMALS FEED (i)

HERBIVORES AND CARNIVORES – WHY THE RABBIT AND THE SHEEP HAVE TO EAT SO MUCH MORE THAN THE CAT AND THE DOG – WHY A LION'S BODY LOOKS SO MUCH LEANER THAN A ZEBRA'S – WHAT YOU CAN GUESS FROM LOOKING AT AN ANIMAL'S TEETH – A BIRD CHEWS ITS FOOD IN ITS STOMACH – CHEWING THE CUD

IT doesn't matter whether the animal is as large as an elephant or as small as a mouse – it must have proteins and carbohydrates and fats, and water, and mineral salts, and vitamins. Just like ourselves.



Drawn by L. R. Brightwell

A cat and a rabbit of the same weight. And, below them, their stomach and intestines. Notice how long the rabbit's is in comparison with the cat's.

From Wells, Huxley and Wells' *Science of Life* (Cassell & Co., Ltd.)

But you have probably noticed that, compared with us, animals have a much more monotonous diet. On the whole, they are either flesh-eaters *or* they are plant-eaters – when they are in a wild state, anyhow.

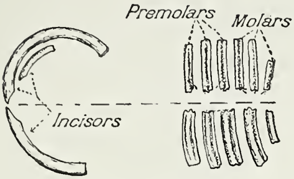
Let us consider the plant-eaters first, the herbivores. Those of you who keep rabbits and guinea-pigs know what they like to eat: dandelion leaves and cabbage and lettuce are the things to give them. The rabbit and the guinea-pig get their protein and carbohydrates from the leaves and stalks, and fats in the form of plant oil, and plenty of mineral salts and vitamins from the fresh green-stuff.

But the cat wouldn't thank you for dandelion leaves and lettuce. By nature the cat is a flesh-eater, a carnivore. If she were on her own, she would catch birds and mice and young rabbits, and eat them. So you have to give the cat some flesh if she is to be healthy. She likes fish, and she likes raw liver very much; there's lots of fat and carbohydrate in liver, as well as protein: and most cats like some milk, which is a very perfect food. And, as I have mentioned already in another chapter, the cat, when she is out in the garden, will sometimes eat blades of grass, carnivore though she is. Quite on her own, she seems to know that she is all the better for some of what the plant can give her in its fresh green leaves.

Of course you know all these things very well. But has it ever occurred to you to wonder why the cat and the dog can get along excellently on two meals a day, or less: whereas the rabbit seems to be eating most of the time? While they are out in the fields, herbivores like cattle and sheep do little else but eat: whereas a lion would think himself fortunate if he had one square meal a day. Why is this? I don't always know the answers to my own questions, but I think I know the answer to this one. What the lion and the cat eat is highly nourishing and most of it is digestible, so even a little goes a long way. But in green leaves and stalks there is a great deal of indigestible, stringy stuff in proportion to the nourishing parts. So the herbivore has to swallow much more food, in order to get out of it the proteins his body requires.

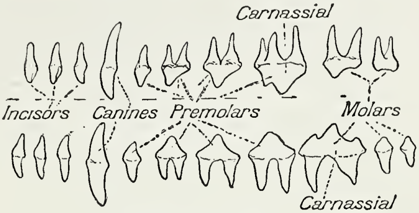
And has it ever struck you what a round, plump body the rabbit has, compared with the cat? A wild cat has a lean, graceful body; and so has a lion. The herbivores, on the other hand – horses and cows, as well as rabbits – always have plump, barrel-shaped bodies. This difference in shape is also connected with the kind of diet. Meat is much more easily digested and absorbed into the blood than leaves and grass are. The rabbits' food is far harder to deal with inside the body than the cat's; and so the rabbit's intestine is much longer than the cat's, to give the rabbit's body plenty of chance to get all the possible good out of the food as it goes down. (*See* picture on p. 123.) So the rabbit's body sticks out at the sides more than the cat's does, because its longer intestine takes up much more room in proportion.

It is interesting too to compare the ways animals eat their food. The different kinds have different sorts of teeth, and they use their teeth differently. You know how the rabbit nibbles with his front teeth and then begins to munch with his jaws: and how the cat uses her side teeth rather than the front ones? On p. 125 are two pictures which I want you to compare. In the left-hand one you see a rabbit's teeth: they have been taken out of the jaws and laid in two rows. (The teeth in the picture belong to the left side of the mouth: you would get the same number on the right side.) The ones above the dotted line belong to the upper jaw, and those below the dotted line belong to the lower jaw. If you count them you will find that there are eight in the top row and six in the lower row: which makes fourteen. Twice fourteen is twenty-eight. The grown-up rabbit has twenty-eight teeth altogether. A grown man has thirty-two teeth. The dog has more: it has forty-two. There is a drawing of the dog's teeth from one side of its mouth in the right-hand picture.



Teeth of a rabbit.

From Dakin's *Elements of General Zoology* (The Clarendon Press, Oxford)



Teeth of a dog.

From Dakin's *Elements of General Zoology* (The Clarendon Press, Oxford)

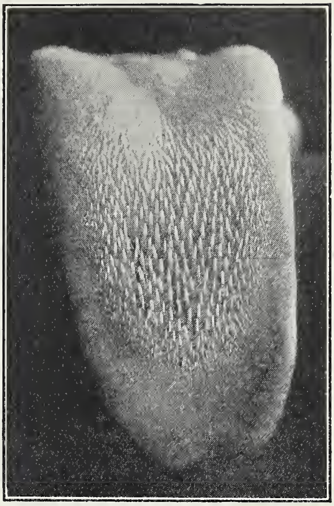
Photo, W. S. Berridge

Mole-rat showing his front teeth.

But it is the *shape* of the teeth I want you to notice especially. You can see at once that the shapes of the rabbit's teeth are very different from the dog's. Now that difference has to do with the different kinds of food these animals bite off and chew. Look at the left-hand picture again. The front teeth – those long curved ones towards your left – are called the cutting teeth or 'incisors': they are the ones the rabbit shows very clearly when it is eating. It nibbles off bits of leaf with these chisel-shaped incisors; and they are such excellent cutting tools that the animal can gnaw with them much harder stuff if it wants to, such as the bark of young trees. Next to the incisors comes a gap. And then come the back teeth, or 'grinders.' These have ridges across their tops, and, as the animal chews, it rubs the ridges of the lower back teeth against the ridges of the upper back teeth, and grinds the food into a soft pulp to be swallowed, all mixed with saliva which is changing the starch of the food into sugar.

Now look at the picture of the dog's teeth again. The dog's teeth are much more spiky than the rabbit's. The incisors are small in proportion and they are pointed. Then notice that there is no gap between them and the back teeth: instead of a gap there is a rather long, very sharp tooth which the rabbit hasn't got at all. This long, pointed tooth is used by the dog for fighting with and for catching prey with. Because it is so characteristic of the dog, this tooth is called the 'canine': but you find large canine teeth in the cat too, and in all the flesh-eaters or very fierce mammals. Next to the canine tooth come the grinders. But in the dog they really cut rather than grind. They have high, sharp points on them which can cut like little knives, and the animal tears up meat with them. One of the back teeth in each jaw is larger than the others: it is marked 'carnassial.' That is the tooth the dog (or the cat, for that matter) uses for crunching bones especially. When you see the cat and the dog eating with the side of the mouth, they are using the blades of these very sharp carnassial teeth.

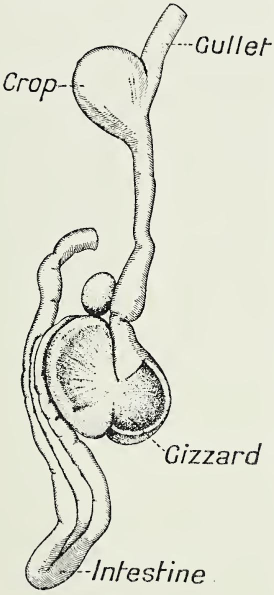
The cat also uses her tongue to get the meat off the bones. When the dog licks your hand, you feel that he has a soft, slobbery tongue: but if the cat condescends to lick you, you feel that her tongue is prickly. On the opposite page is an enlarged photograph of a cat's tongue, and there you see the sharp prickles in the middle of it. With these prickles the cat rasps meat off a bone; and they also come in very useful when she cleans her fur, or her kitten's fur, because then she uses her tongue for a comb.



Photo, R. Malby

A cat's tongue.

Birds have no teeth. They pick bits of food off with their sharp-edged, horny beaks; but they can't chew their food in the mouth. And it is worth mentioning, perhaps, that birds have no saliva with which to moisten the food and begin its digestion before it is swallowed. When you see a hen swallowing hard grains of corn whole, it seems extraordinary that she doesn't suffer from indigestion, for, as we know, an animal's food must somehow be smashed into very small pieces if the digestive juices are to get a fair chance. But if you watch the hen, you will see that she occasionally swallows small stones as well as the corn-seeds: and there is certainly no nourishment to be had out of a stone. If I say that the bird is not swallowing stones by mistake, but in order to help it digest the corn, that sounds very strange; but I must explain that the stomach of a bird is not much like our stomachs or the stomach of a rabbit or a cat. The main part of the hen's stomach is used, not for digesting the food, but for grinding it up. This grinding part is sometimes called the 'gizzard': another name for it might be the mill, because, like a real mill, it grinds the corn into fragments by the help of stones. Look at the picture of the food-canal of a hen: the gizzard is the bun-shaped part and it has very thick, muscular walls. It feels quite hard to the touch, and if you slit it open with a knife, you see that it has thick walls of red flesh: then you come to a small space inside, lined with much harder stuff, and in that space lie the little stones the bird has swallowed. Now, when the food comes down the gullet from the mouth, it has to pass through the gizzard on

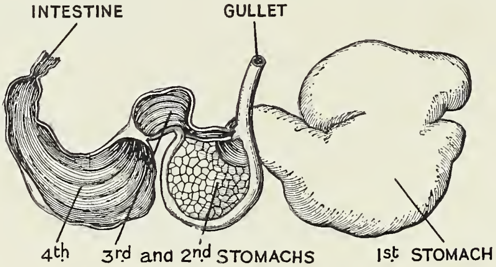


Food canal of a hen.

From Bradley's *Structure of the Fowl* (A. & C. Black, Ltd.)

its way to the intestine: and, as soon as it gets into the gizzard, the muscles of the walls begin to work. They press in on the stones, and squeeze these against the corn-seeds; and the sharp edges of the stones cut into the food and smash it, grind it, into tiny bits. After the gizzard has done its milling, these small bits are allowed to go on into the part of the food-canal which will first digest them and then pass the stuff through into the blood. So you see, though the hen has no teeth, she manages quite well without: we grind up our food in our mouths with our teeth, and the hen grinds it up by means of stones in her stomach. It is just another way of chewing.

Here is a picture of a sheep's stomach: a cow's stomach would look much the same. You will notice there are four parts, like four rooms opening into one another. When a sheep or a cow goes out into the field, it eats grass: it eats at a great rate and without stopping for quite a while, swallowing the mouthfuls of grass almost whole. While it is eating, the grass is going quickly down its gullet into the first stomach. Then the animal goes and lies down in a quiet place, perhaps under the trees. And now it does a strange thing. It brings back the food from its first stomach into its mouth, and proceeds to chew it really thoroughly. It munches and munches and munches with its ridgy grinders, until all the hard grass stalks and the softer leaves are mashed into a pulp and mixed with saliva. There is a tremendous amount of starch in grass, and probably it gets a chance to be partly turned into sugar while the cow (or the sheep) peacefully 'chews the cud.' Then the cud is swallowed: but this time it goes past the door to the first stomach and straight on to the other stomachs; and there it is properly digested.



After Leunis

Stomach of sheep.

From Thomson's *Outlines of Zoology* (Oxford University Press)

Now why on earth should the sheep and the cow have this queer habit? Antelopes and goats have it too, and so have giraffes and camels and deer. Why don't these animals chew the grass once for all when they bite it off the ground? I think that part of the answer may have to do with the fact that all these cud-chewing creatures are defenceless animals on which the large carnivores prey. If they were to stay out in the open, slowly eating grass and chewing each mouthful thoroughly, it would take a long time to get enough for a meal: and all that time they would be in danger, for they would be where their enemies could see them and attack them from the rear. So the idea is to swallow as much as possible very, very fast, and then get away to a safer place with it. There the animal can settle down peacefully to the long, slow business of chewing and digesting the great quantity of food it has fetched away. Of course, it is perfectly true that our sheep and cattle are in no sort of danger from wild animals. But you must remember that these tame creatures we breed on our farms for milk and beef and wool and leather are the descendants of wild cattle and wild sheep; and long ago, there were wolves even in England. Life for the grass-eaters was very far from safe then: they were in as much danger as an antelope would be on the plains of Africa to-day. The danger has gone, but the habit of chewing the cud still persists.

CHAPTER XX

HOW ANIMALS FEED (ii)

WHY EARTHWORMS COME TO THE SURFACE – HOW THE WORM PULLS LEAVES INTO ITS BURROW – DIGESTION OUTSIDE THE MOUTH – THE WORM EATS ITS WAY THROUGH THE SOIL – THE GIZZARD AGAIN – WORM-CASTINGS – THE EARTHWORM AS AGRICULTURIST – SCREEN OUR FOOD FROM FLIES – THE BUTTERFLY'S TONGUE

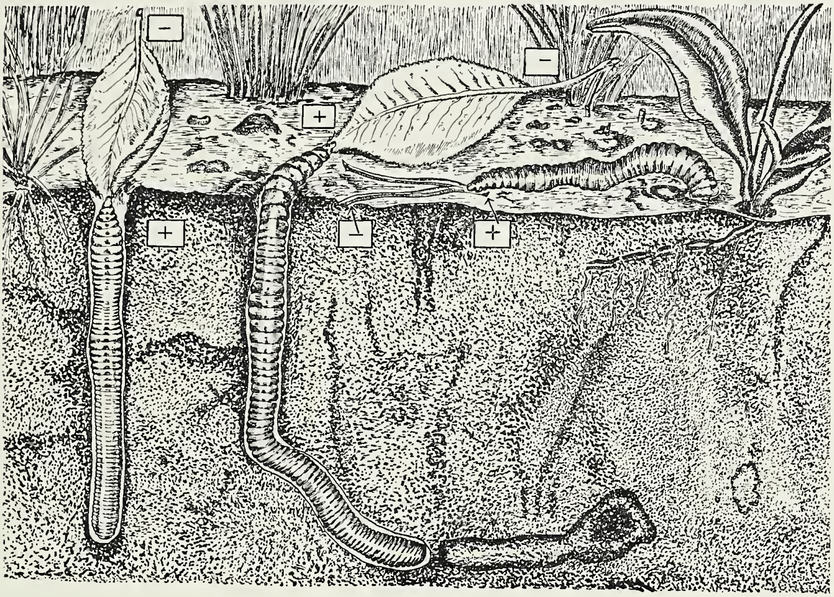
THE animals in last chapter were vertebrates. In this chapter I go on to the invertebrates. Among these, the ways of feeding are many: there isn't room in this book to describe more than one or two. So I shall just pick out a few examples from among the most common and familiar creatures.

Nothing could be commoner than the earthworm. I have read that there are about fifty-four thousand earthworms to every acre of garden soil. So I shall take the earthworm first.

In the picture, we are supposed to be looking at three earthworms pushing their heads out of the ground: it must be night-time in the picture, because it is only after dark that these animals come willingly to the surface. During the day the worm prefers to stay in the darkness of a burrow or tunnel it makes in the ground: the picture shows the earth cut away in front so that we can see the parts of the earthworms that are in the burrows, as well as the parts that are reaching out beyond the surface. There is a very good reason for the earthworm's staying down below during the day, for it is then that the birds, its worst enemies, are on the hunt for it. The worm waits to come up until darkness falls and the birds have mostly gone to sleep.

In mild, damp weather the worms are not far below the surface, even during the day; and in the early morning especially, they have a habit of lying with their heads quite near the entrance to their burrows, enjoying the warmth as the sun comes up. They are careful to hide the entrance to each burrow with a plug of fallen leaves or by a little heap of stones: but the sharp eyes of birds are already spying about for them, so the early morning is rather a dangerous time. You know the proverb, 'It's the early bird that catches the worm!'

Night is their safer time: and if you go out then with a shaded light, and treading very softly, you may see lots of worms stretched out from their holes, feeling this way and that with their heads. Worms do sometimes leave their holes altogether and creep along over the surface of the ground: you can see their tracks on a fine gravel path, especially after a wet night. But generally they prefer to keep their flattened tails inside the entrance, so that they can quickly draw themselves back into safety, should things suddenly get dangerous. If you let a beam of light from your lamp shine on the worm, or if you shake the ground with too heavy a tread, the worm shoots back into its burrow.



Earthworms dragging leaves and pine-needles into their holes. The labels with the sign + on them are at those ends of the leaves that the worms are seizing.

From von Uexküll and Kriszat's *Streifzüge durch die Umwelten von Tieren und Pflanzen* (Julius Springer Verlagsbuchhandlung, Berlin).

You can see what the earthworms in the picture have come up for. They have felt about with their heads for fallen leaves, and they are dragging the leaves into their burrows. They seem to find the leaves by touch. They haven't any eyes to see them with: and anyway it is dark. When it finds a dead leaf, the worm opens its little toothless mouth and sucks in one end, and then it shortens its body and drags the leaf down. It draws in most of the soft part of the leaf, but usually one end is left sticking out above ground. You can often see where an earthworm's hole is, by noticing a tuft of leaf-stalks or leaf-tips sticking out of the earth and plugging the entrance. If you pull this up, you will find the hidden parts of the leaves, decayed and slimy.

An interesting thing is that the worm, though it cannot see, seems able to judge by the 'feel' of the leaf which is the best end to take hold of. If you take a number of different kinds of leaves and try to pull them with pincers, one by one, into a glass tube about the width of an earthworm's burrow, you will find that, while some kinds go down most easily stalk first, others go down best if you pull them by the tip. It depends a lot on the shape. And certainly if you take hold of almost any leaf by the side, and try to pull it that way into the glass with your pincers, the leaf crumples and won't go down smoothly. You would think the worms knew this, for they seldom make the mistake of taking hold of a leaf anywhere but by one of the ends. Sometimes the worms drag pine-needles into their burrows. Pine-needles come off the tree in pairs. As you can easily understand, a pair of pine-needles will go down a tube most smoothly if you take hold of it by the base: which is what that third worm, on the right of the picture, is doing.

What is the use of these dead leaves and fallen pine-needles to the earthworm? I have already explained that the sticking-out stalks or tips will help to block the entrance to the burrow and so make it harder for the bird to get at the worm. Then it seems that the leaves are also used to line the burrow: they make a nice, soft lining which prevents sharp stones from scratching the worm's body. The third thing the worm wants from the leaves is food.

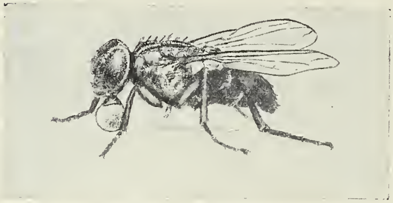
The earthworm has no teeth or jaws, only a small mouth with soft lips. So it cannot bite off a piece of leaf. What it does is to pour from its mouth on to the leaf a fluid it makes in its alimentary canal, and this fluid softens and even partly digests the leaf. Then the worm sucks off mouthfuls of the softened leaf and swallows them. It will eat other things besides leaves. If you put tiny bits of vegetables near the burrow – bits of carrot and celery and onion, for instance – the worm will drag them down at night, and soften them and suck bits off. And it will eat chopped-up meat also, for it is not a pure vegetarian.

All day, however, the worms have to stay underground; and in cold weather, or very hot, dry weather, they stay down by night as well as by day. So you may wonder what they get to eat at such times. The explanation is connected with the way they make their burrows. When an earthworm is tunnelling its way along, it actually swallows the soil as it goes. You wouldn't think soil a nutritious form of food ! Some kinds of earth certainly are not – sand, for instance: and you needn't expect to find earthworms living in pure sand. But in what we call rich soil, the soil of pastures and gardens, there is a lot of dead vegetable and animal stuff mixed up with the indigestible mineral stuff: decaying bits of dead leaf, bits of dead roots, and seeds, and small dead insects. These are what the earthworm uses as food when it swallows soil. It has to swallow great quantities even of the richest soil in order to get enough digestible material for its body's needs, and so it makes the most of each mouthful of earth. A special mill, a gizzard, is kept hard at work in its inside, squeezing and grinding the earth into very fine powder, so that all the tiny bits of food that are mixed with the grit can easily be reached by the digestive juice of the intestine.

When earthworms come to the surface at night, it is not only in search of fallen leaves. They come up also in order to rid their bodies of the large amount of mineral stuff they cannot possibly digest. On the grass in the morning you must often have seen hundreds of small heaps of fine earth in coils. These are called 'worm castings.' They are made of the finely powdered earth the worms have cast from the hind ends of their bodies after a meal of soil.

It might not strike you at first that the earthworm is one of the most helpful of animals to the plants. But it is true. And by helping the plants, the earthworm also helps the gardener and the farmer. Of course I don't mean that the earthworm is being intentionally helpful either to plants or to men. But in the course of living in its own peculiar way, the earthworm actually enriches the soil greatly. Imagine 54,000 earthworms in an acre of ground all dragging leaves down into their burrows every night: in the end, this is as good as giving the soil cartloads of leaf-manure. And the thousands of castings thrown up on the surface, gradually, gradually cover over and bury the fallen leaves also. The leaves, whether dragged down or covered, decay in the ground and make it rich in the nitrates plants take in with water through their roots.

Then, another thing. As they burrow, the worms are constantly opening up the soil, and letting in the air and making little passage-ways through which rain-water can get down to the roots, and along which the roots can grow easily. If it were not constantly being opened up like that by the burrowing worms, the upper part of the soil would get caked and stiff: water wouldn't easily pass in and the roots couldn't push down.



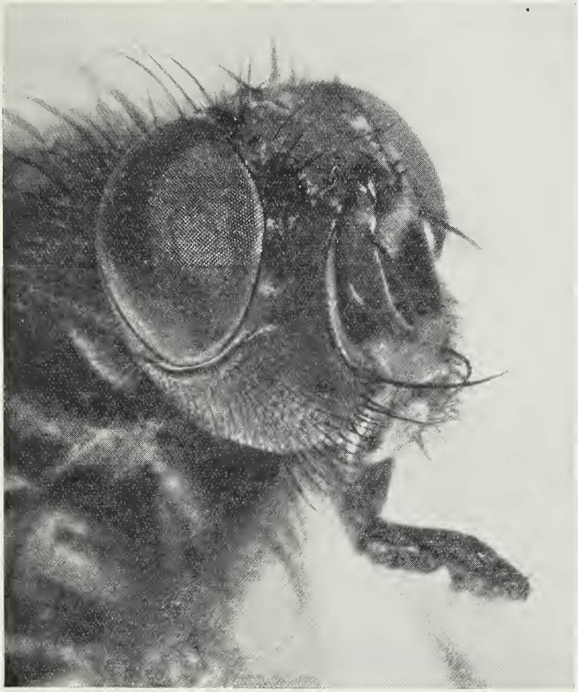
House-fly feeding.

From Hewett's *The House Fly* (*Cambridge University Press*)

The worms' unintentional usefulness does not stop there. Their habit of throwing out finely powdered soil from their bodies on to the surface every night results in their bringing the lower layers to the top, little by little. This is a much slower business than turning the soil over with a spade; but with thousands and thousands of worms working in that way in every field and every garden all the time, it is very effective in the end. It has been calculated that fifteen tons of earth from below are brought to the surface in an acre of ground every year by the worms that live in it.

I could tell you many other interesting things about the importance of earthworms, but I must leave some space for insects. In the picture above you see a house-fly feeding. You must often have watched flies on the sugar or jam, so perhaps you have noticed a little tube that sticks down from under the fly's head. It is quite a short tube, and it widens at the tip like a trumpet. The fly sucks fluid up through this tube, much as we suck lemon-squash through a straw. Usually this feeding-tube is called the fly's 'tongue,' and I shall use that word; but it is not a bit like our tongue, and it is quite outside the head. The fly can feed only on what is fluid; it cannot take in solid food through that tube. I expect you don't believe this because you have often seen flies dabbing their tongues on solid things such as a lump of sugar. But look again at that picture of the fly feeding. Do you see a sort of bubble at the end of the tongue? The fly pours a drop of fluid out from its stomach through the tube on to the lump of sugar. The sugar dissolves in this, and then the fly can suck up the sweet drink it has prepared for itself.

Unfortunately for us, flies are not very particular about what they feed on. They are just as pleased with manure as with sugar, and they may come straight from feeding on manure to finish their meal on the food we are going to put into our mouths. The stuff the fly then brings up from its stomach to moisten what it eats may have in it little bits of dirt from the manure heap. These bits may be so tiny that you can't see them, and some of them may be microbes which, if you swallowed them in any quantity, might make you ill. That is why it is wise to put covers over the food in summer when there are lots of flies buzzing about, and there should always be a bit of muslin kept over the milk that a baby is going to drink. The fly hasn't got to moisten the milk, of course, for that is fluid already. But there may be little bits of dangerous dirt on its body or legs, dirt that stuck to it in the manure heap when it was feeding there, and these come off in the milk if the fly falls in while it is finishing its meal.

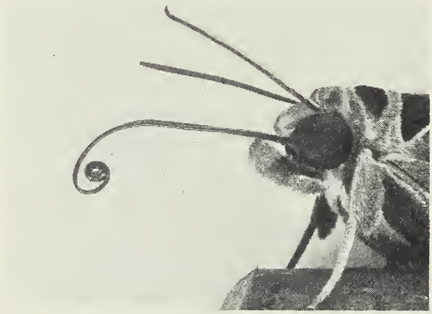


Photo, Dr. Croy

Side view of fly's head showing the right eye and the tongue.

Bees and butterflies and moths are very clean feeders, unlike the house-fly.

They don't drink anything but fluid from the flowers, the fluid that we call nectar. They also have a sucking-tube to feed by, but the bee's tongue is longer in proportion than the fly's tongue, and the butterfly or moth's tongue is so long that, when it is not in use, it is coiled up like a watch-spring under the insect's head. Some people call the insect's tongue its 'proboscis.' We also call an elephant's trunk a proboscis. And really the butterfly's feeding-tube does look more like an elephant's trunk than like a tongue. But the elephant does not feed through his proboscis, of course – though he may pick up food and water with it. The elephant's proboscis is his nose.



Photo, H. Bastin

Head of a moth. The insect is uncoiling its tongue preparatory to taking food.

CHAPTER XXI

NEWS OF THE WORLD

THE WORLD WE KNOW IS A WORLD OF THE SENSES – THE POSITION OF THE SENSE-ORGANS – THE ANIMAL'S SENSE-WORLD IS DIFFERENT FROM OUR OWN – THE NERVOUS SYSTEM – YOU CANNOT SEE WITHOUT A BRAIN – INSIDE INFORMATION – THE USE OF A STOMACH-ACHE

HOW do animals get news of the world? Well, how do you get news of the world?

I can imagine you saying, 'By reading newspapers, of course,' and thinking my question rather idiotic, for it seems to have nothing to do with animals.

But wait a minute. What does one mean by 'news'? Surely what one means is 'the latest information about things that are happening in the world.'

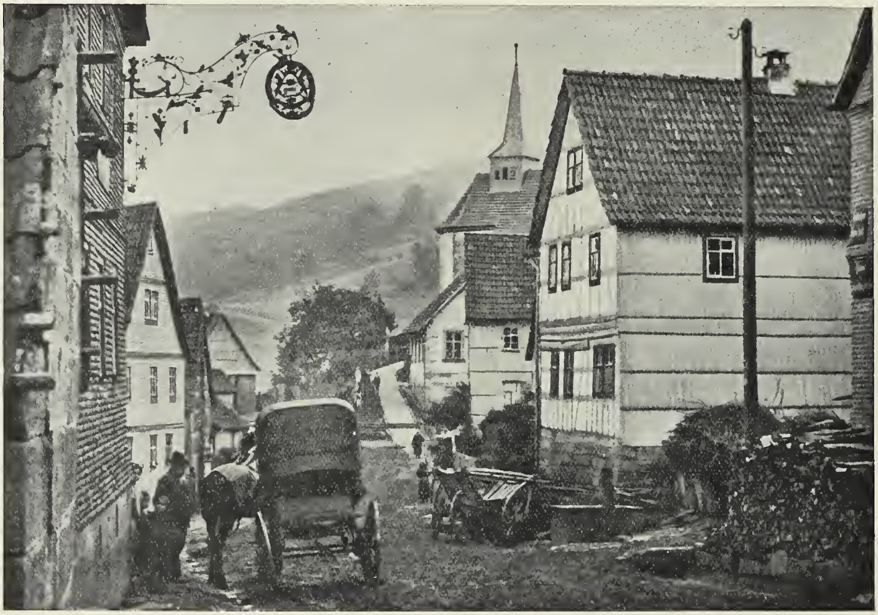
We can read a printed page to get this information. The animals cannot read. But please remember that we get the information from the printed page by using our eyes. And if we were blind, we should have to depend on the wireless for getting our news by using our ears. Or else we should read by passing our sensitive finger tips over raised-up letters and gradually spelling out the words; then we should be getting the information by touch.

All this is just one way of explaining that the only means by which a human being can get *any knowledge at all* of what is going on outside his own body is through what we call the 'senses.' When you read, you use your eyes and depend on the sense of sight: when you listen to the wireless, you use your ears and your sense of hearing: when the blind man reads 'Braille,' he uses his skin and the sense of touch.

Add to these senses the sense of balance and the senses of taste and smell, and you have our only ways of getting to know what is happening. A man deprived of his senses would be like a prisoner in a black dungeon, cut off from all news of the world.

Animals get the news of their world just as we do, through their senses. Eyes, ears, nose, tongue and skin are the sense-organs of the cat and the rabbit, just as they are yours and mine. The cat and the rabbit see, hear, touch, smell and taste, and by these means they get to know what is happening. And then, just like ourselves, they act in accordance with the information they have received. 'The living being is sensitive to stimuli, and it makes an effective response.'

You will notice that the sense-organs of ourselves and of the animals are on the surface of the body, so as to be as near as possible to the outside world from which the information is coming. And the most important sense-organs are placed on the head, which is the part that goes in front as the animal moves about. An army always has its advance-guard of scouts to collect information.



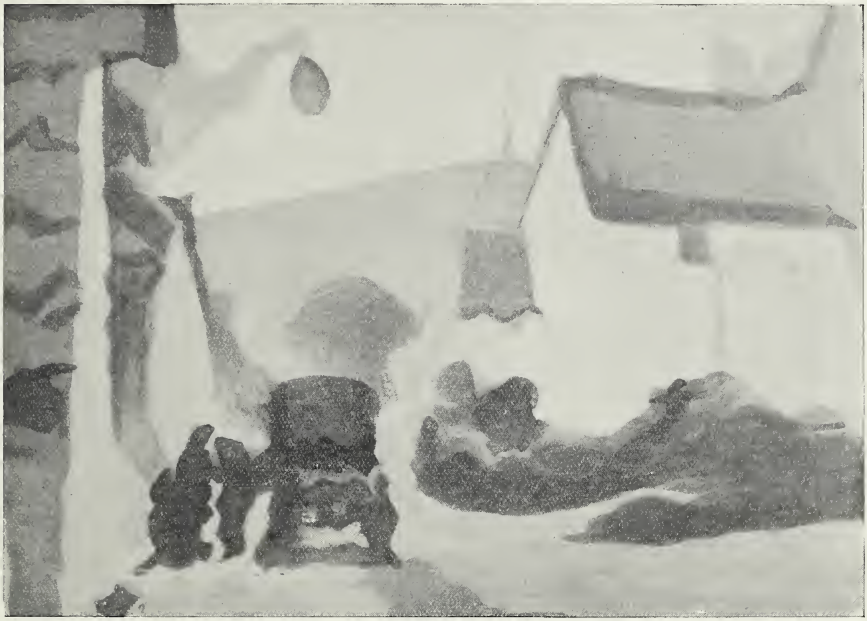
A. Photograph of a village street.

From von Uexküll and Kriszat's *Streifzüge durch die Umwelten von Tieren und Pflanzen*
(Julius Springer Verlagsbuchhandlung, Berlin)

It is impossible for us to imagine a world quite different from the world of which we get news through our own sense-organs. But it may well be that many things are going on in the world which escape us altogether because we haven't got the special sense-organs capable of noticing that kind of thing. And undoubtedly some sorts of animals are provided with extra sense-organs, and so get news that never reaches us at all.

You know that dark-brown line along the side of a haddock's body? All fishes have this line, though it doesn't show so well in some as it does in the haddock. We call this the 'side-line,' and we know it is a sense-organ of some kind. But we and the land animals haven't got a side-line, so it is impossible for us to know how it feels to have one and what the under-water world news is that the fish gets by means of it.

And when you consider invertebrate animals – insects, for instance – you find peculiar organs on their bodies which look as though they were extra sense-organs: but these are so unlike our own that we can only guess what they are for and what sort of information the animal gets through them.



B. The same street as *perhaps* it appears to a fly.

From von Uexküll and Kriszat's *Streifzüge durch die Umwelten von Tieren und Pflanzen* (Julius Springer Verlagsbuchhandlung, Berlin)

Even among the animals most like ourselves, the 'ordinary' senses are developed in very different degrees. Dogs, for instance, have a far, far better sense of smell than we have, but their eyesight is not nearly so good. The information that the dog depends on is largely smell-information; and so the dog's notion of the world is bound to be very different from a man's. A mole cannot see, and the underground world that it inhabits must be mainly a smell-and-touch world. I am going into this in the chapters that follow. All I want to explain here is that the same world must seem a very different place according to what senses the animal has to depend on.

The next thing to realise is that unless there were nerves in the body, the sense-organs would be of no use whatever. To every sense-organ white threads called nerves are attached, and if you were to follow these through the body of a dead animal, you would find that they all end in the brain. The brain is really the most important part of the whole apparatus dealing with news. Let us go back to our sleeping cat by the fire. You call to the cat, and if it is not too sound asleep, it lazily opens its eyes: it has heard a familiar sound. But it was not enough that the sound-waves made by your voice should reach the cat's ear-drums. It was not the ears that 'heard.' The cat would have heard nothing if it hadn't had a brain in its head. What happened was that the brain got a message through the nerves from the ears – a news message that said, 'There is a sound coming from outside.' Then, in response, the brain sent out a message to the muscles of the eyelids, telling them to open the eyes. As soon as the eyes were open, a picture of the room was made in them, and now a message went by the nerves from the eyes to the cat's brain telling the brain about the picture. With its brain the cat then noticed the saucer of milk in the corner, and sent nerve-messages to the muscles of the legs to make them send the body running across the room for a meal.

If the cat had not been hungry, though, I doubt if the information-picture of the food would have interested it sufficiently to make it get up. But the cat's brain was also getting a message from the stomach, a message about emptiness, and the brain interpreted this message as a hunger-pain. So it is not only from outside that animals (and human beings) get information: they get some information from inside themselves as well. From the muscles and joints especially do these messages come in all the time. Usually we are conscious of the messages from the rest of our insides only when something is going wrong. You know nothing about what is happening in your stomach, for instance, unless it is empty or unless you have indigestion: a bad stomach-ache is warning news to the brain that something has gone wrong with the works, something that may be dangerous for your body if it is not quickly put right.

CHAPTER XXII

THE SENSE OF TOUCH

THE SKIN AS A SENSE-ORGAN – TOUCH, IN INVERTED COMMAS – WHERE THE TOUCH-CORPUSCLES LIE – TESTING FOR TOUCH – THE PART PLAYED BY HAIRS – THE CAT'S WHISKERS – FEELERS

THE part of an animal's body that is most directly in contact with the outside world is, of course, the skin – the skin and the things that grow out of the skin, such as hairs. It is not surprising, therefore, that the skin should be a very important sense-organ. Even if an animal has no conspicuous sense-organs at all – no eyes, no ears, no nose – it still has its skin to feel with. You might call the skin the most general sense-organ, for all animals feel with the skin to some extent.

What information do we get through the skin ? It is usual to speak of the skin as an organ of the sense of touch, and it is about touch that I am writing this chapter. But I think it would be fairer to put the word touch in inverted commas – 'touch' – because really what we learn through our skins is more than just about the contacts and pressures of what comes against our bodies. It is with the skin that we also feel changes in the temperature of the outside world: and the skin is especially sensitive to pain.

The nerves that come to the skin end in little sensitive blobs. Some of these are sensitive to heat: some are sensitive to cold: the others are the actual touch-spots. They are called touch-bulbs or touch-corpuscles. When these are stimulated, excited, by pressure from outside, the message goes to the brain that the skin is in contact with something. The touch-corpuscles are so small that they can be seen only if you look at a slice of skin under the microscope: one is shown in the picture on p. 109. You will notice in the picture that it is not on the very surface of the skin: the touch-corpuscles lie in the deeper layer, where the blood-vessels are. The outer layer of the skin is just a tough covering, which has no sensitiveness at all: its duty is to protect. Wherever there is much pressure or rubbing on the body, this outer layer grows very thick indeed, and the part becomes much less sensitive than the rest because the touch-bulbs are so deeply buried under the protecting layer. When you get a blister, the white part is this outer layer, which gets raised up by fluid: and under the fluid is the red sensitive layer. You prick the blister with a needle to let the fluid out, and you feel nothing while you do this. But if you let the needle go deeper, then you feel it quickly enough.

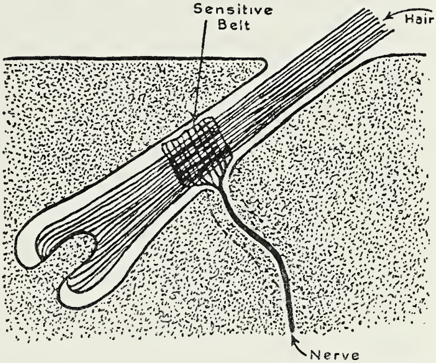
All parts of the skin are not of the same sensitiveness. Some are best for feeling cold and some for feeling heat; and some are much better than others for feeling contact and pressure.

The best of the true touch-spots are on the tips of the fingers, the tip of the tongue, and the lips. The backs of the fingers are much less sensitive: and one of the least good parts for touch is the middle of your back between the shoulders. You can easily test this for yourself. Take one of those measuring instruments called dividers, separate the two points a little way, and then lightly place the two points simultaneously on the skin of some other person, who must keep his eyes shut so that he does not see how far you spread the dividers. Then you ask him to guess whether he has been touched by one point or by two. If you have placed the dividers on his lips or on his finger tips, he can feel the two points *as* two when they are only one twenty-fifth of an inch apart. But at that distance apart he will feel the two points as *one* if you place them on the back of his hand: you have to separate them a good deal farther if he is to feel that there is more than one touching him. And the points will have to be nearly three inches apart if he is to feel them as two distinct things when you put the dividers on his back between the shoulders. It is interesting to try the dividers experiment with several people and compare the results: you will find that even between individual human beings, sensitiveness to touch varies a good deal.

In the chapter on getting news I said that we are also made aware of what is happening in our insides, and especially of what is happening in our muscles and joints. The sense-organs responsible for giving us this inside information are made on much the same plan as the touch-corpuscles of the skin, and they are connected with the central nervous system by nerves in the same way.

The hairs which jut out from the skin play an important part in touch-sensations. I don't mean that the hairs themselves are sensitive: they are made of horny, dead material. But they are connected with touch-corpuscles in the skin, as you see in the diagram. When something comes in contact with the hair, and it is moved to and fro in its pit in the skin, this movement excites the sense-organs attached to the hair, and a message accordingly is sent away from the skin by a nerve. If you pass the fingers of one hand ever so lightly to and fro across the tips of the little hairs on the back of the other hand, you get the touch sensation very distinctly, although you have not come in direct contact with the skin itself.

The hairs on the body of a human being are so small and so sparse that the skin seems naked, and the use of the hairs for the touch-sense is, in us, comparatively slight. But think how important it may be to animals covered all over with hair. Many of these furry animals also have special long strong hairs projecting beyond those of the coat, and these have great value for touch-sensations. They are usually on the head, and there we call them the whiskers. In a wild state, the cat goes hunting at night; and although she has very good eyes and a very keen nose and a wonderful sense of hearing, that isn't enough for what she has to do. She must move very softly if she is not to scare away the field-mice she is hunting. She moves softly on her cushiony feet, treading gently so that the careless cracking of a twig shall not raise the alarm. She comes to a hole in the hedge through which she must pass. It is very, very dark there under the hedge, and she cannot see whether the hole is wide enough for her body to get through without making the twigs crack. This is where her whiskers come in useful. In the picture you see how they stand out well from the cat's cheeks, and spread out to the width of her body. The cat's whiskers are not just for ornament, I assure you: at their roots in the skin is a rich supply of touch-organs. Now, in the darkness of the night, when the cat puts her head through the hole in the hedge, she is judging the width of the hole with her whiskers. If the tips don't come in contact with anything and give her the sensation of touch, she knows that the gap is wide enough for the rest of her body to creep through without making any noise. But if the whiskers touch



Drawn by L. R. Brightwell

Root of a hair with its touch-organ and nerve.

From Wells, Huxley and Wells' *Science of Life* (Cassell & Co., Ltd.)

Photo, Charles Reid

Wild cat hunting at night.

something at the sides, she knows the hole is too narrow; she draws back her head then, and goes farther along the hedge to try for a wider place.

For insects the sense of touch is probably more important than any other sense. The whole surface of an insect's body has special touch-places on it where the little hairs or bristles show; but the chief organs of touch are the two feelers, the antennæ, on the head. If an ant loses its antennæ, it can no longer converse with its friends by means of touch.

Insects are not the only small animals that have special touch-organs on their heads. Think of snails and slugs, for instance. The snail puts out its four feelers – its horns, as we call them – and, as it crawls along, it is constantly touching things with them and finding its way about by the sensations it gets through them. (*See* picture on p. 53.)

The earthworm's skin is so sensitive to the vibrations in the sides of its burrow that even the light tread of an approaching bird will sufficiently shake the earth to give the worm a warning to withdraw. And some of the small creatures have such sensitive bristles on their skins that they can feel with them the disturbances in the air made by sounds.

CHAPTER XXIII

HOW ANIMALS TALK TO ONE ANOTHER

ADAM'S APPLE – SOUNDS AND WORDS – ANIMALS' SOUND-MAKING IS LIKE A BABY'S – THE DOG UNDERSTANDS WORDS THAT INTEREST HIM – PARROT LANGUAGE – WHERE THE BIRD'S VOICE COMES FROM – THE FROG'S AMPLIFIER – THE GRASSHOPPER SPEAKS WITH ITS LEGS – THE CONVERSATION OF ANTS – THE BEE'S DANCE

WHEN we speak we are doing two things. We are making sounds, and we are shaping the sounds into words. The first part, the sound-making, is done at the top of the windpipe, in a special part of it called the voice-box, or larynx. (*See* picture on p. 61.) Another common name for the voice-box is 'Adam's apple.' If you put your hand on your throat near the top of it, and especially if you swallow then, you can easily feel your voice-box. It is an elaborate apparatus of bits of gristle, very specially shaped, and the parts are worked by a complicated set of muscles. Inside the voice-box are two glistening folds stretched across the space through which the air has to pass out from the lungs on its way to the mouth: these folds have a gap between them. They are called the vocal cords; and the sounds we produce are caused by the air coming up through the narrow gap and making the edges of the cords shake very fast. If you put your finger on the throat of a person who is singing, you can feel their vibration.

By contraction of the muscles fastened to the parts of the voice-box, the cords can be drawn taut, or they can be slackened a bit: in this way, you get sounds of different pitch. For a high sound, the cords are pulled tighter and the air comes up through the gap in short puffs: for a low sound, the cords are slackened and the air moves through more slowly. As one grows up, one's larynx grows too, and the vocal cords get longer: this also gives a deeper note to the voice.

The other thing we do when we speak is the word-making part. The sounds coming into the mouth from the voice-box are shaped by the mouth, with its tongue, teeth and lips – into the separate pieces that we call words. Notice how your tongue moves into different positions, and how you press it against the teeth, and how you curl your lips about, when you are shaping vowels, consonants and the words these compose. Deaf people who get very good at 'lip-reading' can guess what words you are saying by watching how you change the shape of your lips to let the sounds through in different ways.

You can do the two parts of speech-making separately, of course. When you sing a scale, you make the sounds in the larynx, but you don't shape them into words. And when you whisper, you don't use your larynx.

The words we shape from sounds are signs, symbols, for expressing our ideas. As we grow up, we read more, hear of more things, think over them more, and get more ideas. So we have to use more and more words. Our word-store, our vocabulary, increases with our experience. The more a man knows, and the more interests he has in life, the larger should be his vocabulary, and the more he should have to talk about. If you are talking to a very young child, you don't use just the same words that you use to a person of your own age and experience. The child would hear the more grown-up words quite well, of course, but it does not yet know about the ideas they stand for, and so it is not interested and takes no notice.

When it is a mere baby, a child cannot do the word-making part of speech at all. It has to learn all that. But from the very beginning it makes sounds in its voice-box; and these squeals and squawks and gurgles and yells certainly have different meanings, although no words go with them. The baby's interests and ideas are very limited: it is chiefly concerned with food and warmth and being comfortable, so a few sounds with different meanings are enough for its purpose.

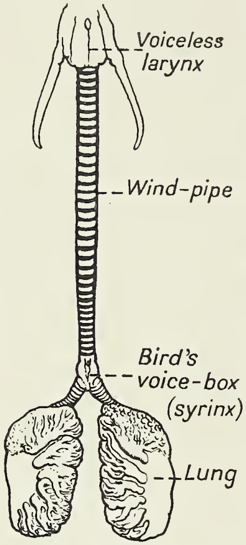
Most of animals' sound-talking is like a baby's in that way. The animal just makes sounds, not words. If you have pet animals and are interested in them, you get to know what a good many of the sounds mean. You know the cat's growling sound when she is angry, and the purring sound she makes when she is pleased: and the 'miaow' she makes when she is hungry is a very different sort of miaow from the one she gives when encouraging her kittens – then it is more like 'pr-r-r-r-*ee-ee*.' On the roof at night she gives piercing yells, which we think simply hideous, but which other cats seem to find very beautiful and full of friendliness.

All these sounds are made in the throat. If you put your finger on the cat's throat when she is purring, you can feel her voice-box working. But it is all a baby-language of sounds: there is no real 'speech.' One reason why animals do not speak, in the strict sense of that word, may be that their lips are not the right sort for shaping sounds: cats and dogs cannot purse their lips up or spread them out, the way we can. But another reason, of course, is that they have fewer things to talk about than we have. Undoubtedly animals talk to one another by sound, but words are not necessary for the comparatively few things they have to say.

A kitten does not take long to learn all the sound-making that will be necessary for it when it is a grown-up cat. And why *should* it learn more than these few, useful sounds that other cats understand ? That is what people are always forgetting, I think, when they say that animals are stupid. Animals are not stupid at all: they are very clever in their own way, and they can talk about just those things that interest them. They talk about food especially, and where to get it; and about warmth and comfortable things like that; and they talk a lot about danger. For all these things are extremely important in an animal's life, especially if it is a wild animal. But things that are important for us are no more important to the cat than they would be to a baby. There are two reasons, then, why cat-language sounds to us so simple and monotonous. First, we do not fully understand what it is all about: we haven't taken the trouble to study it enough, perhaps. And second, the cat is interested in fewer things than we are, and so has fewer ideas to express.

I have chosen the cat as an example, because most people keep a cat and so have a chance to get familiar with her language. And to some extent the cat gets familiar with our language; when we speak to her about things that interest her, she sometimes condescends to show that she has understood our language quite well. Dogs are far better at this than cats. A dog is very sensitive to slight changes of tone in his master's voice. He knows at once from the sounds whether the man is pleased with him or angry with him. And he often gets to know the meaning of actual words. It is not wise to say the word 'walk' in a dog's presence if you don't mean to take him out at once ! The idea for which the word 'walk' is used in human language is an idea that interests the dog very much. But the cat and the dog have been men's good friends for thousands of years; if we and they have come to understand one another's talk a little, it is scarcely surprising. It is much more difficult to guess the meaning of the talk used by wild animals: and anyhow they won't talk much if they think we are listening.

To our human ears, the language of birds sounds far more beautiful than the language of the furry animals. The language of a song-bird seems to us to have much more variety in it. The great time to hear birds is of course in the spring, when they are nesting and bringing up their young ones. And it is not difficult for us to distinguish one bird's song from another's, and so to tell whether it is a thrush or a blackbird that is singing. But it is quite impossible for us to know what all the bird-sounds mean to the animals themselves. A great deal of the singing seems to be done out of sheer happiness, just as we sing to ourselves sometimes when we are feeling very cheerful, and not because we have anything special to say.



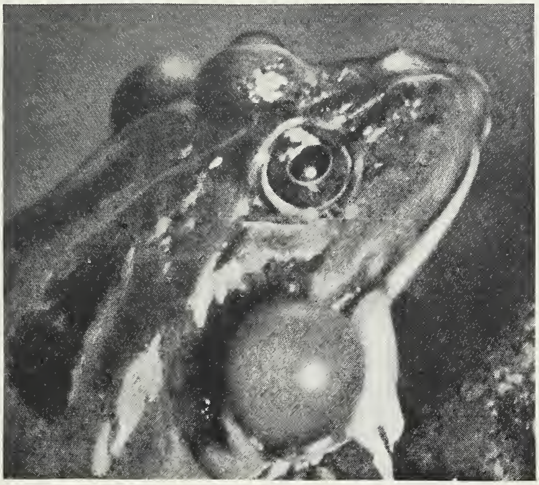
The bird's voice-box is in its chest.

Considerably modified from Thomson's *Biology of Birds* (Sidgwick & Jackson, Ltd.)

Sometimes, however, it is easy to guess that there *is* a definite meaning intended. You hear a blackbird making his lovely whistle: then suddenly he stops and, as he flies off, he gives a curious cackling sound. In our language that cackling sound would mean: 'Look out, you other blackbirds! Here comes the cat!' Or let us imagine that a mother-partridge is out in the field, taking her chickens for a food-hunt. Suddenly she sees a hawk hovering overhead; hawks, as you know, pounce on smaller birds and eat them. The mother-partridge at once gives a peculiar clucking cry; and the baby birds, although they are so young and inexperienced, seem to know just what that means. It is evidently an order to them to lie low and keep quite still until the danger is past, for they all flop down on the ground and remain as still as though they were dead, until the hawk has flown away. Then the mother-bird gives a different sort of cry, which tells them that all's clear; and up they get and begin running about again, looking for food in the grass.

Some birds are very clever mimics. They will learn to imitate the songs of other birds, for instance; and you can teach a bullfinch to whistle a tune. The parrot's own language doesn't seem to be very varied: he shrieks or makes clucking sounds to other parrots. But, using his very muscular tongue, he can imitate human speech so exactly that you would think a person was talking to you. It doesn't follow that the bird has any clear notion of what the words mean: but some parrots undoubtedly connect the sounds of certain names with the people they are fond of.

Now a very curious thing is that birds' voices do not come from the usual voice-box at the top of the throat. The bird's voice comes from away down in the chest. The picture opposite shows a bird's windpipe. At the top of it is the larynx, but there are no vocal cords in the bird's larynx. At the bottom of the windpipe there is a swelling where the windpipe divides into two to go to the lungs. That swelling is where the bird's vocal cords are, and its voice comes from away down there.



Head of a croaking frog.

From the film, *Mystery of Life*, by courtesy of Wardour Films, Ltd.

You know of course that the trumpet on some gramophones is put there to make the sounds louder: it is an amplifier. Some animals have special parts, amplifiers, to make their voices sound louder. A frog is quite a small animal; but if you have ever heard a male frog croaking in the spring-time, you must have been amazed at the loudness of the voice coming from that small throat. Above, you see a frog's head in side view. At the side of the neck is a sort of bag of skin; there is one on each side of the neck close to the larynx. And when the frog croaks to his wife, he blows air into these bags and they amplify his voice.

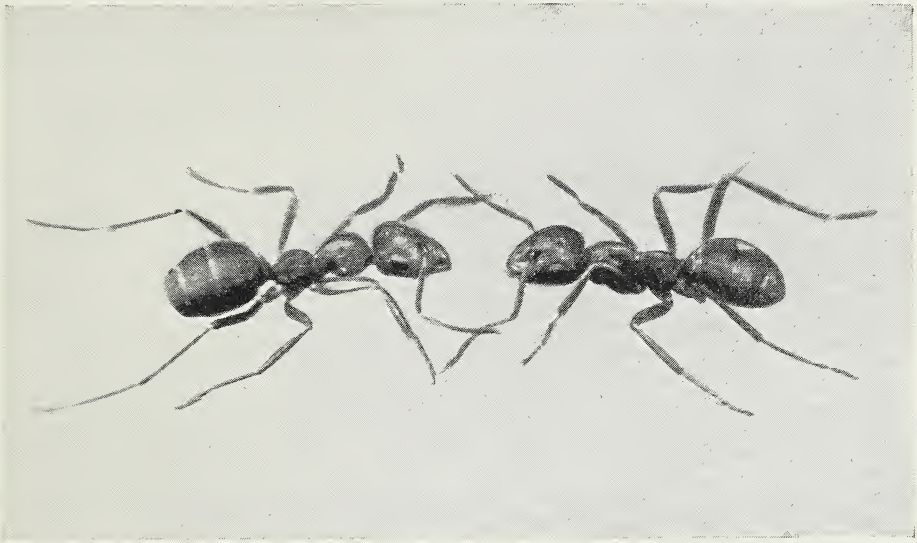
All these animals – cats and birds and frogs – are vertebrates and have their bodies built on the same plan as ours. But some of the invertebrates also have their sound-language. Since insects have no lungs or windpipe, and breathe in quite another way from us, they must make their sounds by means of some very different apparatus. The humming of bees and the buzzing of flies are caused by the insects beating the air very fast with their wings. That is not difficult to guess. But I wonder how many people know where a grasshopper's voice comes from? Here is a picture of a grasshopper sitting on a stick. Like all insects he has three pairs of legs, and you notice that the hind-legs are much longer than the others? With these long hind-legs he gives great leaps into the air. And every now and then he makes a chirruping sound, especially when the sun is shining warmly on the grass where he lives. The other grasshoppers near by chirrup back in answer, and this chirruping conversation may go on and on for hours. The sounds are made by the insect rubbing his long hind-legs against ridges on his wings. To make one's voice with one's legs seems an extraordinary way of talking; but that is what the grasshopper and the cricket do.

Photo, H. Bastin

A grasshopper.

Perhaps many of the small creatures that seem dumb, really have voices, but so high and squeaky that our human ears cannot hear them. There are lots of sounds going on that we do not hear. Some people, not really deaf at all, cannot hear the squeaking of a bat: the pitch of the bat's voice is too high for them.

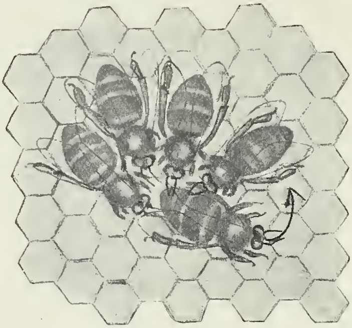
All this time I have been thinking about the language of sounds. But there are other ways of saying things, even among human beings. There is the language of touch. When you shake hands with someone, for instance, that means 'I'm pleased to see you': or when you kiss your mother or your sister, that means 'I'm very fond of you.' These things are understood (by your friend or by your mother) without any sounds being uttered or words being spoken. Human beings have such a rich sound-language that they don't have to use the touch-language very much. Animals use it a great deal. Insects like ants, for instance, make no sounds that our ears can hear; but there can be no doubt that they talk to one another. If you watch one ant meeting another ant on the path, you'll notice how they stop and touch one another very gently with their antennæ. The antennæ make little quivering movements as they do this, and perhaps each kind of pat means something special to the ant that is touched by her friend.



Photo, H. Bastin

Ants in conversation.

Perhaps they are smelling one another, as well as just touching. In the picture called "A bee 'dancing' " we are supposed to be looking at a bit of the bee's honeycomb in the hive. On it there are five bees clustered together. The one on the right, at the bottom, has just come back from collecting honey in the flowers, and she is telling the other four that she has found a good place and advising them to go there too. What she does is to run round and round in circles: this is called the bee's dance. The arrow in front of her head in the picture is put there to show the direction in which she is dancing. She runs round and round in circles; and, as she runs, the other four bees run after her and touch her with their antennæ. By degrees they get very excited; and presently, when she stops her dance, they go flying out from the hive to look for the honey she had told them about. It is impossible for us to know just how that message is given by the dancing bee to her friends. By touch, they can feel that she is running in a circle, and that may be the signal for 'honey' in bee-language. Perhaps they also smell the honey-scent on her body. Anyway, they seem to understand quite well what is meant by the dance-message. The bee does not dance every time she comes back to the hive: if she has not had much luck and comes back without having found a good place for honey-gathering, she goes about in quite an ordinary way, and the other bees do not follow her.



A Bee 'Dancing.'

From Frisch's *Über die Sprache der Bienen*
(Gustav Fischer Verlag)

CHAPTER XXIV

ANIMALS' EARS

THE EAR IS A 'BALANCE'-ORGAN AS WELL AS AN ORGAN OF HEARING – THE EAR OF A JELLY-FISH – GRASSHOPPERS ON THE TELEPHONE – WHISTLING TO A CATERPILLAR – THE SPIDER AND THE TUNING-FORK – THE HUMAN EAR – THE DOG HEARS BETTER THAN WE DO – EAR-TRUMPETS – THE EAR IN THE BIRD AND THE FROG – WHAT THE SLOW-WORM HEARD – EAR-STONES

ONE of the best ways in which we get news from outside is through the special sense-organ that we call the ear. The ear is sensitive to the vibrations in the air that are known as sound-waves. If you were shut up in a vacuum, you could hear nothing because there would be no air to carry the waves across to your ears.

While everybody knows that the ears are the sense-organs for receiving the stimulus of sound-waves, it is not always realised that the ear serves another very important purpose. If we hadn't ears, we should not only be deaf; we should be unable to stand upright, or indeed to balance our bodies at all.

In some animals the ears are entirely for balancing with: in others, their only duty is to receive sound-waves. In ourselves and in most of the vertebrate animals the ear has both duties to perform.

The simplest kind of ear is the ear of a jelly-fish. The common glassy-white jelly-fish with the purple centre, which you often find washed up on the seashore, has eight ears, arranged at intervals round the edge of its umbrella-shaped body. (*See* picture on p. 13.) They are little bags containing small grains of lime in a liquid. When the jelly-fish

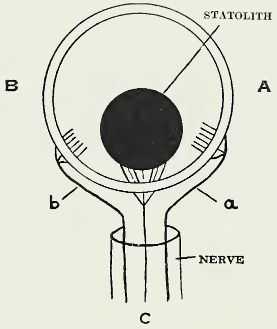
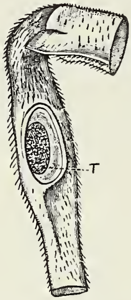


Diagram of the balancing ear of an invertebrate animal. In the position shown, the fibre (c) is stimulated. When the body rolls towards A, the statolith comes to lie on the sensitive hairs connected with (a). When the body tilts towards B, the statolith rolls on to the sensitive hairs connected with (b).

From Hogben's *Principles of Animal Biology* (Christophers).

is alive and floating near the surface of the sea, its body is tilted about by the water, and the lime-grains in its ears (marked 'statolith' in the picture on p. 153), being heavier than the rest, fall against the sides of the little bags in which they lie. They fall against special patches of the lining of the bag which are very, very sensitive to pressure; and this pressure gives the jelly-fish the feeling of its position. To take an extreme case, suppose that the jelly-fish were turned upside-down in the water, its ear would also be upside-down and the lime-grains in its ears would then fall against the top of the bags and press on the lining there. This would give the jelly-fish the signal for 'upside-down,' and it would make muscular movements of its body to bring itself the right way up again. The lime-grains would then fall back to the bottom of the ear-bags, which is their natural position; and the jelly-fish would feel comfortable once more, for its ears would give it the signal of 'right-side-up.'



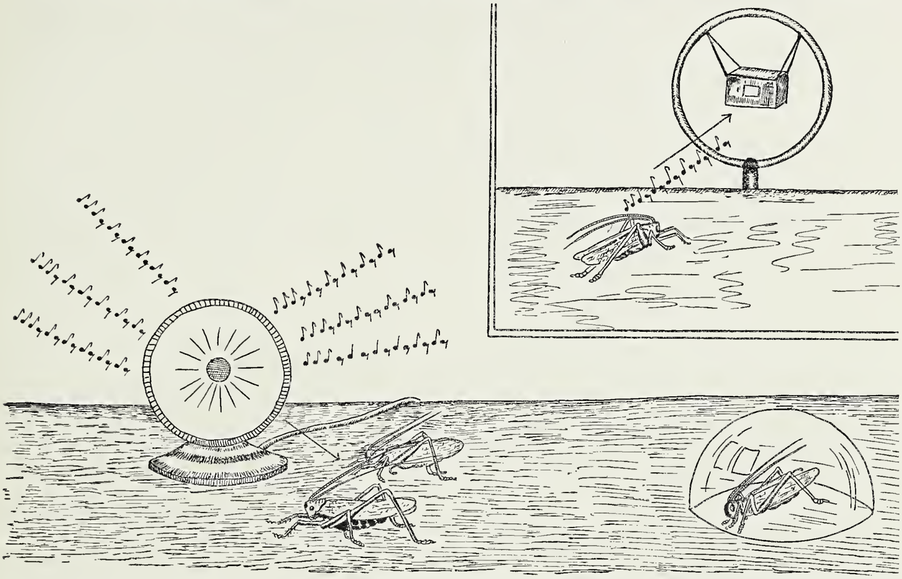
Part of a grasshopper's leg, showing the ear.

From *Cambridge Natural History*, Vol. V, 1901 (Macmillan & Co., Ltd.)

Lobsters and crabs also have ears of this kind – for balance, not for hearing with – one ear at the bottom of each of the smaller of its feelers. But instead of lime-grains, the lobster and the crab have tiny bits of sand in their ears; and after shedding the sand along with its hard skin when it moults, the animal puts a new supply of sand-grains into its ears.

Lobsters, crabs and jelly-fish are silent animals. As far as we know, they do not converse with one another by making sounds; so you would scarcely expect them to have a good sense of hearing. But where animals have a sound language, you may be pretty sure there are ears to hear it. So insects that make sounds probably hear one another. Some insects seem to hear with their antennæ. And some butterflies and moths have ears hidden in the sides of their bodies. The grasshopper has his ear in his hind-leg, just below the knee-joint. On p. 150 there is a picture of a grasshopper, and you see the long hind-legs with their knee-joints up in the air. That picture does not show you the ears; it is too small. But on this page is a picture of a bit of the hind-leg drawn very large, and it shows the ear with its drum: the drum is marked 'T'. The drum is a small bit of tough, papery stuff stretched on a frame, and it vibrates when the sound-waves strike against it. It is especially sensitive to the sound-waves set moving through the air by the chirruping of other grasshoppers near by; and the shaking of the ear-drums in its hind-legs informs the insect that its friends are communicating with it. Then it chirrups back in answer.

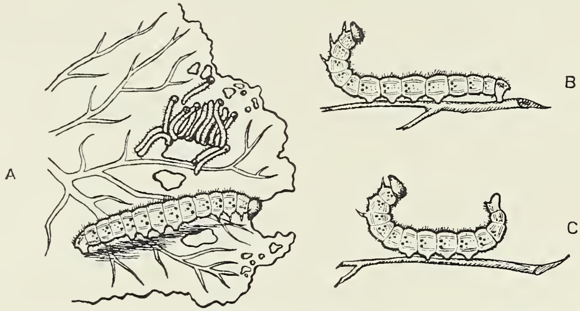
A man made a very good experiment to show that grasshoppers do really hear one another's talk and are interested in it. He had two little cages: and into one he put a number of female grasshoppers, and in the other he put only male grasshoppers. He put the cages in different rooms, so that the insects could not see or smell one another; and then he fitted up a telephone between the two rooms. The part you speak into was put beside the male grasshoppers' cage, and the receiver was put beside the female grasshoppers' cage. Presently the male grasshoppers began to chirrup. And when the females in the next room heard the chirruping sounds coming through at their end of the telephone, they at once went up towards the receiver and seemed very much interested. When the current was cut off and the sounds stopped coming through, they lost interest and went away.



The grasshopper in the picture on the right at the top is chirruping into the microphone, and his friends in the next room (on the left) are listening to his voice as it comes through on their receiver.

From von Uexküll and Kriszat's *Streifzüge durch die Umwelten von Tieren und Pflanzen* (Julius Springer Verlagsbuchhandlung, Berlin)

But it is not always easy to prove like this that an animal is really *hearing* the sound-waves and not just feeling the vibrations with the touch-organs over its whole body. Look at those caterpillars in the picture. In the part marked A, they are just crawling on a cabbage-leaf and eating holes in it. But in B and C, a man has blown a whistle near to them, and immediately the caterpillars have reared up as though disturbed. When the whistling stops, they will lie down again and crawl about as usual. They have no ears, and probably they do not hear the whistling sound: but the sound-waves touch their bodies and shake them a little, and that disturbs them. It seems likely that the tiny hairs on their skin are the parts that are so sensitive to the shaking, because the man who did the experiment noticed that when these little hairs got wet and stuck to the caterpillar's body, the animal took no notice, however loud he whistled.

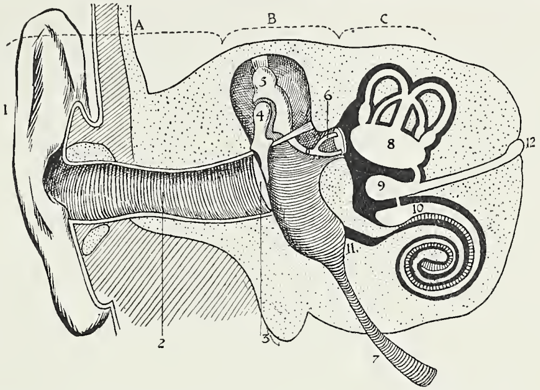


Caterpillars of the cabbage-white butterfly rearing when whistled to.

From Dr. Baier's paper in *Zoologische Jahrbücher*, Vol. 47 (Gustav Fischer Verlag)

Spiders are particularly sensitive to any shaking of their webs. You can see why. For the shaking may mean that a fly has got entangled in the web and is struggling to get free. So when the web shakes, the spider runs out on to the net in the hope of a meal. Now, if you strike a tuning-fork sharply and then put your finger against it, you can easily feel the shaking of the prong that has set the air vibrating and gives your brain the sensation of a special musical note. Strike that tuning-fork near a spider's web: the spider will rush out just as eagerly as though a fly had landed in its trap. The spider has no ears; it did not hear the musical note; it just felt the slight trembling of the web produced by the sound-waves coming from the vibrating tuning-fork.

It is very difficult indeed to discover about the powers of hearing in animals so unlike ourselves as insects and spiders. When we go on to consider the larger animals, it is a good deal easier. Since the vertebrates are all built on the same plan as ourselves, they all have just two ears, placed one on each side of the head.



After Hesse and Weber

Diagram of the human ear. A, outer ear; B, middle ear; C, inner ear. 1, the ear-trumpet (*pinna*). 2, external ear-passage (*meatus*) running to 3, the ear-drum (*tympanum*). On the inner side of this is the middle ear, containing air and communicating with the cavity of the mouth by the Eustachian tube, 7. It contains the three auditory ossicles, 4, 5, and 6, which transmit the variations of the drum to the membranous window, to the right of 6, in the wall of the inner ear. The inner ear is entirely embedded in bone. It contains a fluid, the perilymph; this surrounds the 'membranous labyrinth,' 8, 9, 10, a series of membranous organs containing another fluid, the endolymph. 8, the utricle with the three semicircular canals arising from it, the organ of balance. 9, the *sacculus*, leading to 10, the spiral cochlea, the organ of hearing. Above 11 is a second membranous window which is pushed outwards when the first window is pushed inwards, and vice versa.

From J. Arthur Thomson's *The Outline of Science*, Vol. I (George Newnes, Ltd.)

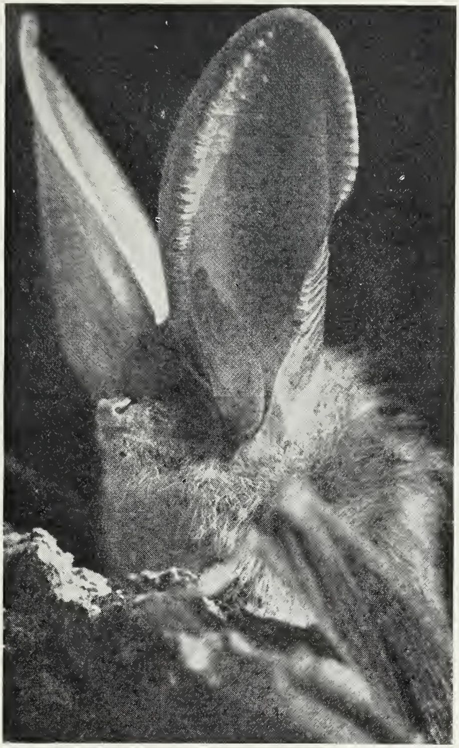
The ear of a human being is an extremely complicated piece of apparatus. The part that shows outside the head (the part one usually calls 'the ear') is really just for collecting the sound-waves and turning them in towards the drum: I shall call it the ear-trumpet (1). The sound-waves then pass along a passageway (2) leading through the side of the skull, and at the end of this passage they come against the drum (3), which blocks it. Beyond the drum is a chamber called the middle ear (B), and from the floor of this chamber a tube leads down into the throat (7). (You know how sometimes when you have a bad cold, you go rather deaf for a time? That is because the tube from your throat to your middle ear has got inflamed and partly stopped up.) If you have found the middle ear, from which that throat-tube leads off, you will now notice three little things (4, 5 and 6) arranged in a chain from the drum across to the inner wall of the chamber. These things are called the ear-bones; and, while the outermost one is fixed to the drum, the third one lies against a very small window in the inner wall, a tiny window made of very thin skin. When the sound-waves shake the drum, the vibrations are carried across the ear-chamber by the shaking of these three little bones, and the innermost one pushes against the little window and makes it shake too. The rattling of that tiny window shakes what lies farther in still; and now at last we come to the really sensitive part of the ear. Everything else that I have described is just leading the sound-waves up to the sense-organ, which is so precious and so delicate that it is shut away most carefully in a special cave in the skull bones, which are very thick and strong just here.

I do not propose to describe the sense-organ in detail. But if you look at the picture you can easily see that it is made of two main parts. The part above (8) has three loops on it, and the part below (10) is wound into a spiral rather like that of the shell of the trumpet snail. The whole thing lies in fluid, marked black in the picture. It is the spiral part that receives the shakings coming from the little window and sends on a message to the brain that such and such a sound has struck the drum. The part with the three loops has nothing to do with hearing – in us, anyway. It is the part that helps us to keep our balance: inside it, floating in fluid, are tiny particles of lime. Though it is so much more complicated, this part of our ear can really be compared to the ear of the jelly-fish, and its way of working is not so very different.

The ears of all vertebrate animals are made on this plan. Some of them haven't got the ear-trumpet part, and some of them haven't got a drum and ear-bones. But they *all* have the very delicate, balancing part with the three loops, hidden away in a little cave at the back of the skull.

Now we might go on to compare the ears of these vertebrate animals with our own, and I especially want to consider how their power of hearing compares with ours.

All the mammals hear very well indeed; and some of them hear much better than we do. Think of the dog, for instance. How quick he is to hear quite faint sounds, and how quick to distinguish between one sound and another! The dog hears his master coming along the street, long before the people in the room do, and he goes running to the door barking with joy. Not only does the dog hear that far-off sound of footsteps in the street, but he can pick out the special sound of his master's footsteps from the sound of all the other footsteps going along. It seems that dogs can even hear sounds to which we are quite deaf. There is a special kind of whistle which, if you blow it, seems to make no sound: but that is merely because its pitch is too high for our ears. Evidently it does really make a sound all right, for a dog will come running when you blow it. And dogs have a wonderful sense of rhythm. Suppose you set an instrument ticking at the rate of 100 beats to the minute, and then change the beat so that the instrument is ticking at 96 beats to the minute. Some dogs seem to hear quite well that there has been that very, very slight change in beat – a change of only 4 ticks per minute. I doubt if a human being could do this, unless of course he had a watch in his hand and actually counted the beats.



Photo, Fischer

The long-eared bat.

You must not expect, of course, that creatures like dogs and horses and cats will like the same sounds that we like, or that they will be interested in music. What they listen for, what they are interested in, are the voices of their friends or of their enemies, and the sounds of crackling twigs or leaves rustling – sounds that may mean some enemy is coming near or that some creature is coming along that will be good to eat.

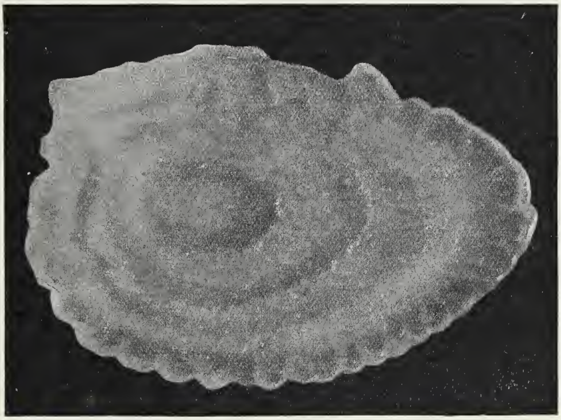
The ear of these animals is really very much like yours and mine. The chief difference, as you know of course, is that usually the outside part, the ear-trumpet, is so much larger in proportion than it is with us: it really often is a 'trumpet,' and not a mere 'shell.' In the rabbit and the donkey and the bat, for instance, the ear-trumpet is relatively enormous. And you will notice how, in all the furry animals, the ear-trumpets stand well up on the head, in a good position to catch the sound-waves. Most of them can move their ear-trumpets to and fro, in the directions from which the sounds are coming. This moving about of the ears is done by special muscles. We human beings have the remains of these muscles, and some people can move their ears a tiny bit; but no one can really move them so that they are in a better position for catching sound-waves. When *we* want to listen very attentively to a faint sound, what we do is to put a hand up behind the ear, so as to make a better ear-trumpet for the time being.

As you would expect in animals that have such a rich language of sounds, birds have very acute hearing. They seem, however, to be able to get along quite well without ear-trumpets. Some owls, it is true, have tufts of feathers standing out at the sides of the head; and these, no doubt, serve to collect sound-waves. But there are no ear-trumpets of flesh in any bird; and you have to part the feathers of the head behind the eye to find the hole that opens into the passage leading to the ear-drum.

The smaller vertebrates – frogs, for instance – don't even have a passage leading to the ear-drum. On the head of the British frog you can see a dark patch behind the eye. That is where the drum of the frog's ear is, right on the surface of the skin. When the other frogs croak to him in the spring-time, the sound-waves made by the shaking of their vocal cords strike on this drum, and a message goes to the frog's brain that his friends are there and calling to him.

Though the frog and the newt and the lizard have perfectly good ears, they often behave as though they were quite deaf. They don't seem to hear when you speak to them; they pay no attention to music, if you play to them on a violin or bang to them on a drum. They may take notice, of course, if the instrument you are playing is resting on the place where they are; because then their bodies are actually shaken by the vibrations, and that disturbs them. They will probably move off, very much annoyed. But that is not hearing through the ear: it is just feeling the vibrations with the whole of the body – a very different matter. Now it is important to remember that when a frog pays no attention to sounds which to us seem very loud or very beautiful, it doesn't mean that the frog's ears are not getting the sound-waves all right. It means that the ear, *and the brain* that gets the messages, are not 'tuned in,' so to speak, to these sounds. The sounds to which the animal's ear and brain *are* tuned in, are the sounds that are of importance to it in its own life. And the animal seldom makes a response to any sounds but these.

I'll give you an example of what I mean. There is a kind of lizard called the slow-worm. A man who kept a slow-worm as a pet tried to discover what it could hear. He tried shouting at it and playing music to it: he made all manner of noise. But the slow-worm just looked very bored, and behaved as though it were stone-deaf. Then someone by mistake left a water-tap dripping in the room where the slow-worm was kept. The sound of the dripping water was very faint. But instantly the animal seemed to come to life and looked quite brisk and eager. At first the man was much puzzled, and wondered why that faint sound of water dripping gently from the tap should so interest and excite his slow-worm.



Photo, Marine Biological Association of the United Kingdom

Ear-stone of a fish. (Magnified.)

From Russell and Yonge's *The Seas* (Frederick Warne & Co., Ltd.)

Then suddenly he remembered that slow-worms like to feed on slugs. And slugs come out and crawl about when it has been raining and the air is damp. So the sound of the water dripping from the tap meant to the slow-worm 'raindrops'; and if there are raindrops there may well be slugs! In fact, the sound of rain is the slow-worm's dinner-bell. And its brain took in that sound all right, because it was important to slow-worm life.

You never can see a fish's ear from outside, because the fish hasn't even an ear-drum. All the fish has for an ear is the deeply hidden part right inside the skull, the part with the three loops on it. Do fishes hear with this ? Perhaps some of them can, a little. But most fishes seem to be really deaf, and their ears are probably just balancing organs. If you get a fish's head from the fishmonger and break open the skull at the back, you will find, right inside the bones there, very pretty, pure-white things which look as though they were made of rough china. They are made of lime and are called the ear-stones. I could tell you some interesting things about ear-stones: for instance, how people guess the age of the fish by counting the number of rings on it. But I must stick to the subject of this chapter, which is about the ear and what it is used for. I do not think the ear-stones are used for hearing with. They move about a little inside the fish's ear as the animal swims, and when they knock against the sensitive lining of the ear, a message goes from there to the brain, a message which tells it how the muscles should be worked to keep the fish's body from tilting over on one side. The ear-stones are part of the fish's balancing apparatus, in fact; and they do the same for the fish that the tiny particles of lime in our ears do for us, and the lime-grains in the ear-bag of the jelly-fish do for it.

CHAPTER XXV

THE SENSES OF SMELL AND TASTE

THE SMELL-WORLD OF A DOG – RECOGNITION BY SMELL – DANGER-SIGNAL AND TRACK-SIGN – SMELLING UNDER WATER – TEST THE BEE'S SENSE OF SMELL – ANTENNÆ AS SMELL-ORGANS – THE OAK-EGGAR MOTH – TASTE IS LARGELY SMELL – TASTING WITH THE SKIN

IN comparison with the ear, the smell-organ is a simple piece of apparatus. In ourselves it consists of two small patches of very sensitive skin, each measuring about a quarter of an inch across, which lie away up inside the nose at the very top – one patch for each nostril. As we breathe, the air coming in through the nostrils passes across these sensitive patches, and in the air are very minute particles of scented stuff which have floated off from things in the outside world. These particles come against the sensitive patches and we get a sensation of the particular smell of the thing from which they were given off.

The smell-organs lie rather above the main air-passage through the nose: and if we want to pay special attention to the smell of something, we draw in the air more energetically than usual in little, equal sniffs, so that it gets right up to the smell-organs. When you have a cold in the head, the nose-passages get a bit inflamed and blocked, and, for a time, you seem to lose the sense of smell because the air with the scented particles cannot get properly to the sensitive patches.

We human beings think we have a very good sense of smell. But, as I was saying, our smell-patches are only one-quarter of an inch square. In a dog, which is a much smaller animal than a man, each smelling-patch would be as much as ten inches square if it were spread out flat: that is to say, it has forty times the area of ours. And we actually find that the dog's sense of smell is very much more highly developed than our own. In fact, the dog depends on his nose far more than on his eyes for news of the outside world.

You know how it is when you take your dog out for a walk. He is a great companion in the house; but as soon as he is out-of-doors he pays very little attention to you, and he forgets about everything but the smells of the road. He looks about him very little. He runs along with his nose to the ground, or he stops to sniff here and there, or to sniff at the bodies of other dogs he meets. The smells that interest him are not the smells that we should think delicious ! And, in a general way, the scents that are so sweet to us mean nothing to a dog. Why *should* they ? A dog is not interested in roses and lilies: flowers mean nothing in a dog's life. A dog is interested in food, and in his dog-friends and his dog-enemies, and in the people with whom he lives, and in the people who might come and steal things from his master's house. So it is the smell of food and animals and people that interest a dog when he goes for a walk.

Very quickly a dog gets to know the smell of one man from that of another, and he especially loves the smell of his master. To our weak noses, a clean man who has a hot bath every day doesn't seem to have much of a smell: but the dog can sniff the smell of that clean man in the air for some time after the man has passed, and can track him down by it. Spaniels and setters and pointers are especially good at tracking by smell, and so they are used by hunters to smell out where the game is. The bloodhound is one of the keenest smellers: and he is sometimes used by the police to find a criminal. They give the bloodhound a coat or something that the criminal has worn, and the animal sniffs the coat until he gets to know the smell of that particular man. Then the police set the bloodhound loose, and he goes running about with his nose to the ground until he comes across the special smell of that criminal. Then he will follow it along the path the man has taken, and, with luck, he may be able to track him all the way to the place where he is hiding from the police. The dog is not following the man's footprints with his eyes: he is smelling the tiny scented particles that floated off into the air from the man's body as he ran along the path. In the same way, St. Bernard dogs are used in the Alps to guide search-parties who are looking for some man who has got lost in the snow and may die of cold or starvation if he is not brought back to safety.

Now I am sure you can see how very important this sense of smell must be to an animal living in a wild state. We give our dogs their two meals a day and they live safely in our houses. But if a dog has no master and goes back to living in the wild, he has to depend on himself for getting food by hunting, and he has to depend on himself for keeping out of the way of his enemies. His keen nose helps him then: that, and his keen sense of hearing. The various kinds of animals he kills for food – rabbits and rats and so on – each have their own special smell. And suppose our dog were living in some country where there were big, fierce animals like lions and tigers; he would have to know their smells too, so that he could keep out of their way and be safe from getting killed and eaten by *them*.

If you go near a horse, you can smell the peculiar smell that all horses' bodies give off: and it is quite different from the smell a cow has. But our noses are not good enough for us to be able to recognise the smells of horses and cows at any distance. Some animals, though, give out such a strong scent that even we can recognise it in the air for some time after they have passed. One day this summer I was walking along a path in the country, where the air was full of the sweet smells of heather and bracken. Quite suddenly I got a whiff of something very different: a sort of sharp, hot smell – difficult to describe. But I knew what it meant, and I said to myself, 'A fox !' A fox must have crossed the path a little while before I came along, and the strong, characteristic smell of its body was still hanging in the air.

All mammals that are in danger from stronger beasts are constantly sniffing the air when they are out in the open. If you were in Africa, you might see a herd of antelopes out on the plain, eating the grass. Quite suddenly they stop feeding, and go bounding away at a tremendous pace. Obviously they have been frightened by something and are running for safety. But frightened by what ? There is nothing dangerous in sight. Ah, but there was a lion crouching in the thicker grass near by; and the wind blew the smell of that lion across the plain to the feeding antelopes. At the first whiff of that dangerous smell, in terror they fled away.

If you were a hunter going out to stalk a stag, you would be wise to crawl towards it with the wind blowing in your face. For if the wind is blowing towards the stag from where you are, the animal will get the human smell and will be off before you can even get your gun to your shoulder.

When the hounds are after it, a deer will sometimes attempt to break the smell-track its hoofs are leaving behind it on the ground. I have seen a hunted deer deliberately get into a stream and wade up it for some distance before bounding away again across the moor. The running water will carry the scent particles down-stream, and when the hounds come up to the water, they 'lose the scent' and go running up and down the bank in perplexity. They will perhaps pick up the scent again after some time spent in nosing about; but the time they lose in this way may be just long enough to give the swift stag the advantage that it needs and enable it to get away to safety.

The mammals, then, recognise their food or their enemies by the smells the skin gives off; and they are helped to recognise their friends by smell, too. So, in addition to the language of sounds and the language of touch, there is also a sort of smell-language, and it is immensely important to these creatures.

It is difficult to imagine what smelling under water would be like, for we cannot smell anything under water. Nor could a dog. But some fishes undoubtedly hunt their prey by smell. Even if a shark has lost its eyes, it can smell out its food from a distance of several yards, and will go straight for it just as though it could see.

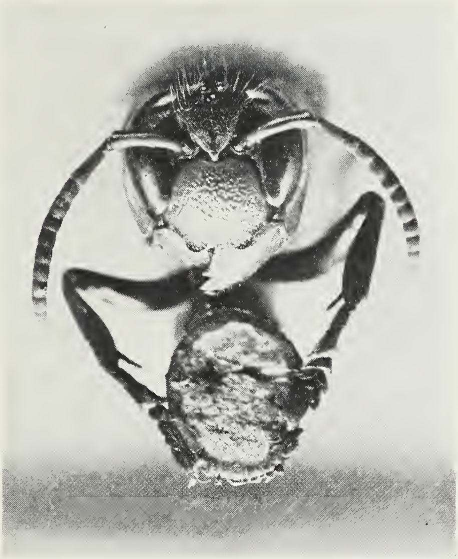
Birds, on the other hand, have a very poor sense of smell. Birds depend mostly on their wonderful eyesight, and on their powers of hearing. Perhaps one reason why they don't use smell is because, when they fly high up in the air, it wouldn't be possible to follow scents, with the wind blowing them all about and mixing them up.

But we know that many of the small animals, such as insects, have an excellent sense of smell. It is always more difficult to plan experiments to show this, in the case of animals whose bodies are made so differently from our own; but the following is a plan that any of you might try who keep bees.

Take four little boxes with lids, and make a round hole in each lid, just big enough for a bee's body to get through comfortably. The boxes must be exactly alike, and the holes must all be the same size. Now, put into one of the boxes some oil with a sweet, flowery scent; and add a little sugar and water, which the bees like to feed on. Put nothing in the other three boxes. Place the four boxes in a row near where the bees are: and presently you will find that they begin coming to the one with the sweet smell and the sugar: they leave the other three alone. Change the order of the boxes as you like: the bees will still choose the one with the sweet smell and the sugar. They cannot see the sugar, for it is hidden in the box; so it does seem likely that they are guided by the smell of the oil coming out through the hole.

You can easily understand that to have a keen sense of smell is very important for an animal like a bee, which lives on the sweet juice of flowers and on flower-dust. The special scents of the flowers help to guide the insect to the places where it will find food. In another chapter I shall explain that bees also have good eyesight. They see the flowers, and they could see your four boxes perfectly well. But since the boxes all looked exactly alike, it must have been the smell that guided them to the right one.

Since insects haven't got noses, they must smell with some other part of the body. It seems likely that they do most of their smelling with their antennæ. You may remember I mentioned in Chapter XXII that the insect uses these for touching things with: but it also seems to use them instead of a nose. Look at the picture of a wasp's face, and notice the antennæ. If that wasp were feeding, it would be touching the food all the time with its antennæ, to smell whether what it was going to eat were good for it. The antennæ of an insect, are jointed rods, sometimes carrying side-branches and with little hairs on them. Overleaf there is a picture of moths' heads showing the feathery antennæ: you will notice that the male moth's antennæ are larger and handsomer than the female's. Moths, and especially the males, seem to have an extraordinary sense of smell, and it seems pretty certain that the antennæ are the smell-organs. These insects fly about chiefly in the evening, when the light is so dim that their

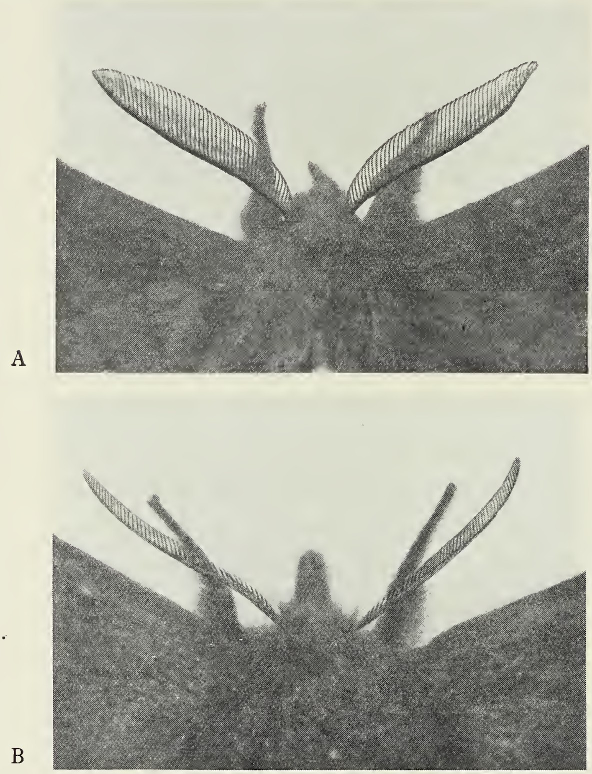


Photo, H. Bastin

A hornet's face, showing the eyes, the antennæ and the jaws. (The insect is holding on to a broken twig with its front pair of legs.)

eyes are not of great use to them: and it is in the evening that the flowers moths like to visit give out their sweet scent most strongly.

Moths can also smell things that to us seem scentless. They can smell out their friends from quite a long distance. The following story illustrates this. Some men took a female moth of rather a rare kind, and one evening they put her in a box covered with muslin on a table in their sitting-room. They opened the window about a foot at the top, and they sat there smoking their pipes and talking. In less than one hour, seven male moths of the same uncommon kind as the female in the box had come into the room through the window and were flying about in search of her. To the men, the female had no scent at all: but to the male moths the scent coming



Photo, H. Bastin

A. Head of a male moth.

B. Head of a female moth of the same species.

from her body was far stronger than the smell of the tobacco smoke in the room, and they must actually have smelt her from far away outside the house.

If an insect has the misfortune to lose its antennæ, it appears unable to notice smells any more. This, and the fact that insects with the best developed antennæ *seem* to have the best sense of smell, leads us to suppose that the antennæ are the smell-organs of these noseless animals. But one must not forget that perhaps insects, which are so unlike ourselves in so many ways, may have extra senses of which we know nothing. Some people have even suggested that the male moth finds the female, not by smell, but by some sort of wireless message.

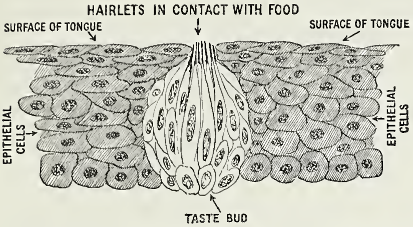
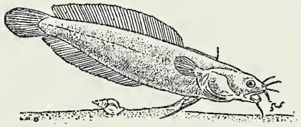


Diagram of a taste-bud, highly magnified, lying in the surface of the tongue.

From Argyll Campbell's *Readable Physiology and Hygiene* (G. Bell & Sons, Ltd.)

I have put taste in the same chapter with smell, because in human beings the two senses are so closely connected that we often confuse them. Chop up an apple and an onion into small bits: then shut your eyes and hold your nose, and then get someone to put first a piece of one into your mouth and then a piece of the other. You will not find it easy to tell which is which, from the taste. As soon as you stop holding your nose, you know the difference between them easily enough. (And you know how tasteless everything you eat seems when you have a cold in the head and your nose is temporarily stuffed up?) When we say that an apple and an onion have different tastes, then, we really mean that they have different smells. As a matter of fact, there are only four tastes – sweet, bitter, sour and salt. All the other flavours we enjoy or dislike are not tastes, but smells.



Drawn by L. R. Brightwell

Tasting outside the mouth. The rockling can taste things with its feelers and with two of its fins as well as with the inside of its mouth.

From Andrade and Huxley's *Science and Life* (Basil Blackwell)

In ourselves the sense of taste is connected with the tongue, in the skin of which are set tiny sense-organs called taste-buds. But in some animals the sense of taste is not restricted to the mouth: some fishes are able to taste with outside parts of the body such as the fins. And it seems likely that insects use their antennæ for tasting things with. As sense-organs an insect's antennæ do almost everything for it but see.

CHAPTER XXVI

THE ORGAN OF SIGHT

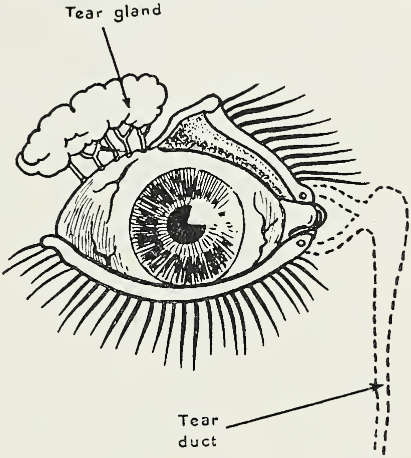
THE EYE-BALL – THE EYE LIKENED TO A PHOTOGRAPHIC CAMERA – FOCUSING – ACCOMMODATION – STEREOSCOPIC VISION – ITS ADVANTAGES – COLOUR – PERHAPS THERE ARE MORE COLOURS THAN THOSE IN THE RAINBOW – COLOUR-BLINDNESS

THE sense-organ of sight is the eye: and before I discuss the sense of sight in animals, the best plan will be if I describe the chief parts of the human eye and explain a little how these work. That will give us something to start from when we go on to consider in the next chapter how animals look at the world.

When you think of a person's eye, I am sure you think of much more than the eye itself. You think of the eyelids and eyelashes, and the eyebrows perhaps as well. But these are just parts of the face round the eye. The eye itself is a ball about an inch in diameter, sunk in a hollow of the skull, which we call the 'socket,' and moved to and fro in the socket by six special muscles. The eyelids always partly cover the eye, even when it is, as we say, 'open': they shut out the light when we want to rest: they are moist inside and their flickering movements help to prevent dust from sticking to the front of the eyeball. The eyelashes are there to keep larger particles from getting in easily: and the eyebrows on the ridges above the socket catch the sweat as it runs down the forehead and turn it aside so that it doesn't run on to the eyeball. If you could take away all the surrounding parts, you would find that one person's eye looks very much like another's. It is the eyelids and other surrounding parts that give the eye what we call its 'expression.'

The greatest possible care is taken, then, that the eye shall be protected from harm, for it is the most precious sense-organ that we have, and our sight is the sense on which we most depend. There is a proverb which says, 'In the country of the blind, the one-eyed man is King.' To have even one eye would give a man so much more information about the world than his blind companions could ever get, that he would be in a position to order them about and run the whole show.

The eye has sometimes been compared to a photographic camera. Lining all the back of the inside is what may be compared to the sensitive film or plate for taking the picture: this part is known as the *retina*. By means of it we are made sensitive to what are called light-waves – waves that are longer than heat-waves and 'wireless,' but shorter than 'ultra-violet' and 'X-rays.' The light-waves enter the front of the eyeball and then go through a round hole called the *pupil*: this is the black dot in the middle of the coloured part of the eye. The pupil can be made larger or smaller by the contraction of muscles that lie in the coloured part of the eye, the *iris*: the iris acts like the shutter, or diaphragm, of the camera and regulates the amount of light that gets through the pupil into the back of the eye. The only other really essential part of a camera (besides the opening for light, the sensitive film and the shutter) is the *lens*, which focuses the light-rays on the sensitive film. And in the eye there is a lens, just as in the camera. It is a clear glassy body, slung up by supports just behind the iris; and the light-rays coming through the pupil are focused by the lens on to the retina. The picture that the lens throws on the retina, is upside-down and right side left – just as in a magic lantern. Though the picture comes on to the retina in this unnatural position, the brain which gets the message about it from the eye changes it about, so that we get the right-way-up impression.



Drawn by L. R. Brightwell

The human eye with the upper lid cut and turned back. The tear gland is shown, which makes fluid to wash across the eyeball and keep it clean. On the right-hand side is shown, by dotted lines, the tube from inside the eyelid for draining away this fluid into the nose.

From Wells, Huxley and Wells' *The Science of Life* (Cassell & Co., Ltd.)

In the diagram on p. 173, the eye has been cut longways and we are looking into the inside. X marks the middle of the pupil: you see the iris, the lens behind that, and the eye-lining that we call the retina. The dotted lines from the lens are supposed to be rays of light.

You must also notice now that there is a clear bow-window in front of the pupil: this is just the front of the eyeball bulged out a bit and made transparent. It is marked *cornea* in the picture. The rest of the outside of the eyeball is not transparent: it is what we call the 'white' of the eye, and it protects the delicate parts inside. It is in two layers really, and the inner layer (the one next the retina) contains a lot of brownish-black stuff. You know how your camera is black inside, to prevent the light-rays getting reflected from the lining of the box. It is the same idea here. The black inner coat of the white of the eye absorbs the light and prevents disturbing reflections being made of the rays that come in through the pupil. The spaces inside the eye – between the bow-window and the lens, and all the part behind the lens – are filled with transparent fluid and jelly.

At the back and immediately opposite the middle of the lens, is a place marked 'yellow spot': this is the best part of the retina for seeing. Alongside it is another place, marked 'blind spot': as the name suggests, that is the one place on the retina where no picture can be formed. The blind spot is the place where the nerve runs out from the back of the eyeball, and joins it to the brain. And here also lie blood-vessels, bringing blood to feed the eye and oxygen to enable it to do its work.

Supposing you are taking a picture of some friend, and your camera is just a small cheap one – you have to walk back just the right distance before you take your snap. If you are too far away, or if you are too near, the picture you take will be all blurred – it will be 'out of focus.' In the more expensive cameras, there are special screws by means of which the front part carrying the lens can be moved forwards or backwards, and that saves you the trouble of walking to and fro yourself. Now, if the eye works like a camera, there will of course be the same trouble about getting the picture quite clear and sharp, in focus, on the retina. In ourselves, and in all the other mammals, this is done by altering the *shape* of the lens itself. The lens, though solid, is elastic and can be slightly altered in shape. In the picture, do you see a dark patch marked *ciliary muscle* ? That really runs all the way round the front part of the eye, outside the iris, and is connected to the lens by delicate strings. Supposing you want to look at something very near, what you unconsciously do is to contract the ciliary muscle, and this slackens the strings and allows the lens to become shaped rather more like a ball. When we look at things in the distance, the ciliary muscles are relaxed, and the lens goes back to the shape it has in the picture. You can understand, then, that it is not possible to have near and distant objects in sharp focus at the same time: either the distant object will be blurred while you look at the thing close at hand, or else the near object will be out of focus and blurred while you gaze into the distance.

When you are looking at a near object, you do more than just change the shape of your lens by contracting your ciliary muscles. By means of the muscles that attach the eyeball in its socket, you move the eyeballs slightly, so that the two pupils are turned a trifle nearer to one another: the nearer the object is brought to the eyes, the farther round the pupils have to be moved towards the nose, and if the object is held right up against the nose your 'squint' becomes very obvious indeed. While this is happening, the pupils get a little smaller. The word 'accommodation,' then, is used to include all that happens to the eye as we change over from distance-seeing to near-seeing. For distance-seeing the human eye has to make no special muscular efforts: but as you will understand from what I have been saying, very fine muscular adjustments have to be made to

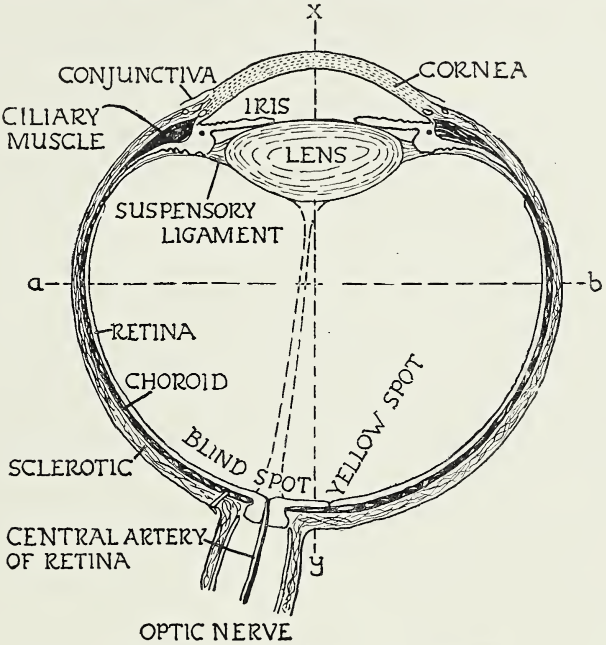


Diagram of a man's right eye cut across.

From figure in Haldane and Huxley's *Animal Biology* (Clarendon Press) which was based on figure in Schafer's *Essentials of Histology* (Longmans Green & Co., Ltd.)

'accommodate' for seeing close at hand and getting the object into sharp focus. Most people who had very good 'long' sight when they were young keep this long sight when they get older, and they can see far away to the horizon without difficulty. But they may have difficulty over the accommodation for seeing near things: and one of the reasons for that is because their eye-lenses get a bit stiff with age and cannot so easily change shape when they are required to do so.

There are not many animals that can look at a thing with both eyes at one time, in the way we can. I shall say more about that in next chapter; but I want you just to notice now that our having both eyes on the front of the face and being able to direct them both on one object, gives us a wonderful power of getting a good idea of the shapes of things, and of judging small distances very accurately. If you shut your left eye and look at a thing with the right one, you will get a slightly different picture from the picture you get if you shut the right eye and look at the same thing with the left. When both eyes are looking at the thing at one time, they are each getting a slightly different view of it, because they are seeing it from different positions on the face. In the brain which gets the message about the pictures from the two eyes, these two pictures are combined into one; and it is a much more 'solid' picture than if the picture-message came from one eye only. If you have ever compared an ordinary photograph with what you see in a stereoscope, you will know what I mean. In the apparatus called a stereoscope, two photographs are placed side by side and we look at them together through peep-holes. The photographs are of the same thing, but are taken from *slightly* different positions; and when we see them combined by the stereoscope, we get a view that looks much more natural than the single photograph does. Suppose it is a photograph of a room. The single photographic picture of a room always looks rather flat and you have to 'pretend' a good deal in order to imagine yourself walking about in it; in fact, it is so unlike the room as your two eyes see it in reality, that a totally uneducated person might not recognise what it is meant to be. But seen as a double picture combined by the stereoscope, the room looks like a place into which you really could walk: all the tables and chairs and things 'stand out' and look solid, and you could easily imagine yourself getting into the picture and walking about between the bits of furniture and taking books out of the picture of the book-case.

Our eyes then, do this combining of two flat pictures every time we use them together. We get a solid, stereoscopic view of the world and the things in it, and this makes it much easier for us to handle objects neatly and judge small distances correctly. Try threading a needle when you have one eye shut: you will find it much harder to do than it is when you use both eyes. And people who have lost the sight of one eye are terribly handicapped when it comes to playing games like tennis or cricket.

Before I leave the human eye, just a few words about colour. Our eyes are not only sensitive to light and capable of giving us a picture of the outside world – they also give us a coloured picture. Our eyes are sensitive to the light-waves that give us seven colours – violet, indigo, blue, green, yellow, orange and red. Now undoubtedly there are waves beyond the violet side of the rainbow – these we speak of as ultra-violet and X-rays; and there are rays beyond the red side of the rainbow – these we speak of as heat rays and 'wireless' rays. But these rays beyond the rainbow do not give the human eye the impression of light or of colour. Do not let us forget, however, that these rays are there, and that very possibly animals with eyes different from ours may get impressions of light and colour from them. It is important to remember that, even among human beings, the impressions about colour are so different. Quite a lot of people are more or less 'colour-blind': it is very common to find people – boys and men much more often than girls and women – who cannot distinguish red from green. This is not only unfortunate for these people, because they miss so much of the beauty of the world: it is positively dangerous sometimes, for traffic-signals and railway-signals are generally of these two colours, and, if a man cannot tell one from the other, he may make a very terrible mistake when he is driving, or even when he is crossing a street. *Complete* colour-blindness in a human being is uncommon; but I shall explain in the next chapter that it is probably the normal thing among some kinds of animals. To the completely colour-blind person, the world must look like a stereoscopic photograph – all in shades of black, grey and white.

CHAPTER XXVII

HOW ANIMALS LOOK AT THE WORLD (i)

SEEING DIFFERENTLY – CATS' EYES – A THIRD EYELID – THE SIZE OF EYES – THEIR POSITION ON THE HEAD – A BIRD'S-EYE VIEW – SEEING UNDER WATER – COLOUR-SENSE IN DOGS

WHEN I was thinking of a name for this chapter, I was first going to call it 'How Animals see the World,' or perhaps 'How the World looks to Animals.' But then I realised that wouldn't be fair: because honestly I cannot tell you what the world looks like to a cat or a dog; and still less can I tell you what it looks like to a fly or a snail. No human being can know these things for certain: we can only guess.

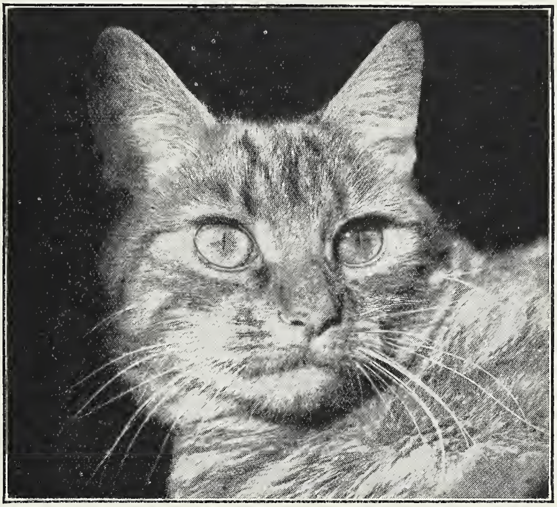
I cannot know exactly what the world looks like even to *you*, because I can never look out through your eyes. It is quite likely, for instance, that we see colours rather differently. Though our eyes are really so much the same, and though we have the same sort of brain to get the messages from the eyes, yet we human beings do not all see the world alike. It is to be expected then, isn't it, that a dog or a bird will see the world more differently still ?

So all I can do is to point out some of the interesting things you can notice for yourself about animals' eyes: and I shall tell you some of the guesses we make about the pictures animals get of what is around them.

All the vertebrates have their eyes made on the same general plan as our own. All the same chief parts are there; but there is a lot of difference in the detail.

The eyes of the furry animals are the most like ours. But even they have their own special differences. The iris is usually much larger in proportion: unless your dog rolls his eyes up at you, you can scarcely see the whites. Then the pupils are not always the same shape as ours. In us they are black dots; but in the cat they are narrow black slits when the light is strong. Look at the picture of the cat's head and notice the shape of the pupils. That cat is facing a strong light to be photographed, but in a dim light the pupils will open out large and round to catch all the light-rays possible. (What shape are a lion's pupils ?)

Then, about eyelids. Most vertebrates have a third eyelid, in addition to the two we have. You see this third eyelid very well in the cat sometimes, especially when she is drowsy and slowly opens her eyes. It looks like a bit of half-transparent greyish skin across the eye, towards the nose side. It lies under the other two eyelids, which are much thicker and are hairy. The third eyelid can be moved to and fro across the front of the eyeball like a shutter, and probably it is used for keeping the eye moist and clear of dust. In a dead hen you can see the third eyelid very well, and you can push it to and fro with your finger and see how it works. Why haven't we got a third eyelid like these other animals? I do not know. We have just the remains of one, and it shows better in some people than in others. If you ask someone to turn his right eye to the right while you look into it, you will see a little pink bit of skin in the corner of the eye nearest to the nose. (I don't mean the red dot, but the paler skin beside that.) That little bit of pink skin is the remains of a third eyelid.



Photo, Adamson

Head of a cat.

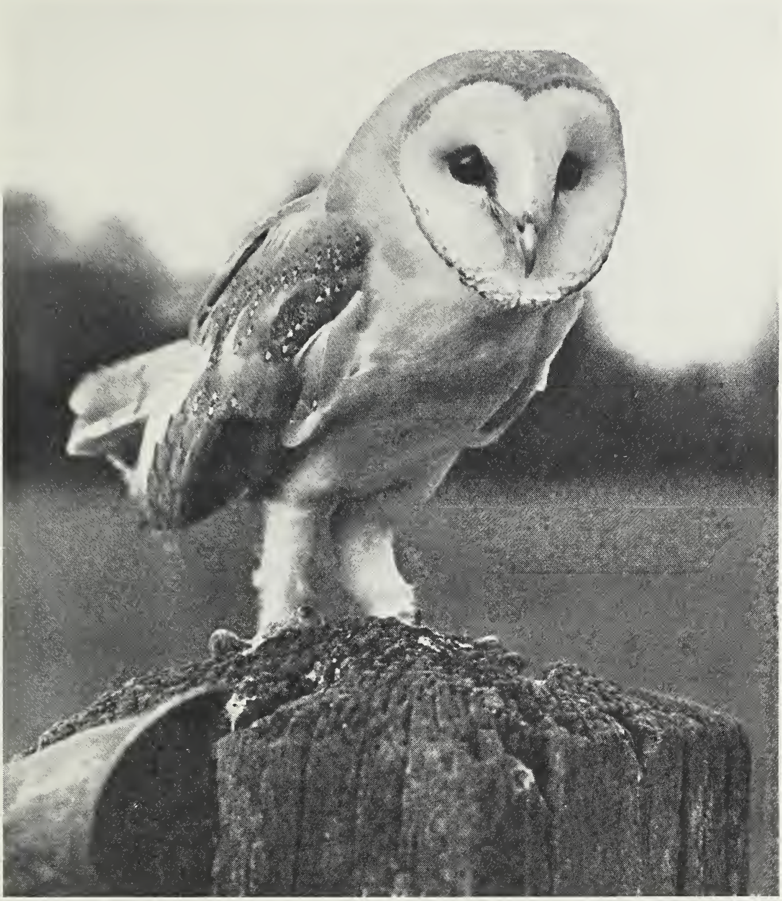
Talking about eyelids, have you ever noticed that fishes haven't got any, and so cannot shut their eyes? Perhaps one reason why fishes haven't got eyelids is because they live under water, and that keeps their eyes nice and moist and washes off any scraps of dirt that might get in. But just because fishes cannot shut out the light and so have to sleep with their eyes open, I sometimes think it isn't very kind to keep a goldfish in a globe in a bright light all the time. You see, if the goldfish were swimming in a pond, the light would come on it from above and wouldn't strike directly into the eyes: but the glare the fish gets in its eyes when you keep its globe on the table must be very trying for the animal.

Have you ever thought about the size of animals' eyes ? The eye of a child of seven is as large as that of a full-grown person. After about seven years of age, the human eye does not get bigger. So a child's eye is large in comparison with its body, and a grown-up's eye is small. This seems rather strange, because generally, as people grow, all their parts increase in size together. The answer to the puzzle is that, *for good seeing, an eye must not be below a certain size, but it does not see better for being larger than that.* This helps to explain why big animals seem to have small eyes and small animals large eyes. An elephant's eye is a big eye, of course; but it is tiny in comparison with the size of the elephant. A rabbit, which is a small animal, certainly has smaller eyes than many animals have; but they are very large indeed in proportion to the rabbit's body. If the rabbit's eyes were as small in proportion to its body as the elephant's eyes are to his, they would be about the size of pin-heads. Now an eye the size of a pin-head can't see things clearly at a distance of more than six feet. A mouse has an eye about the size of a pin-head, and the mouse is very short-sighted. That doesn't matter to the mouse, because it is a night animal, and anyhow it depends more on its senses of smell, hearing and touch than on its sight. But the rabbit must be able to see well in the day-time for some considerable distance around it.

The elephant's eye, though it looks small in such a big body, is really quite a big eye, as eyes go. It is quite big enough for good sight. If an elephant were to have eyes as large in proportion to its body as the rabbit's are to the rabbit's body, they would be at least the size of soup plates ! But an eye the size of a soup plate probably wouldn't work a bit better than an ordinary-sized eye; and enormous soup-plate eyes might easily get damaged by the elephant when it went crashing headlong through the thick and tangly jungle.

Another thing to notice is the position of animals' eyes on their faces. Why is it that some animals – rabbits and horses and pigeons, for instance – have their eyes one on each side of the head: while other animals – lions and monkeys and owls, for instance – have their two eyes much nearer together, on the front of the head ? I don't know the whole answer to that question; but some of it perhaps I can explain.

Think of horses first. In a wild state, horses live out in the open in herds, munching the grass. They are very timid, defenceless creatures; and all the time they are feeding they are in danger from wild beasts which



Photo, E. J. Hosking

Owl. Notice the position of the eyes.

may be crouching near, waiting to spring on them. As well as sniffing the air to get the danger-smells, they also keep a very sharp look-out for any *movement* in the long grass or in the bushes. Now, if your eyes are one on each side of your head, and especially if they bulge out a little, the way a horse's do, you get a much wider view all round than you would if your eyes both looked forward only. You see both sides of the country at once, one side with one eye and the other side with the other eye. You get two pictures, and you can even see a bit over your shoulder without turning round. It is much more difficult to be taken by surprise if you have so wide a view as a horse gets, or an antelope, or a rabbit. At the first movement that he sees, the animal dashes off to safety.

But there's no doubt that this wide view of the distance has one disadvantage. It is rather hazy: the shapes of things are not very clear or 'raised-up' and the animal can't judge very well just how far off they are. The sight is good for noticing movements rather than for judging solid shapes. Now, on the other hand, animals with both eyes on the front of the head can look at one thing with both eyes at once; and this gives a much better picture, for things look more solid and the animal is much better able to judge their distance away. The cat and the lion and the monkey and the owl have lost the very wide view that the horse has and the rabbit; but, with their near-set eyes looking together at one thing, they can see its shape better and they can tell how far off it is. The cat and the lion and the owl are, all of them, carnivores who seek their prey in a dim light; and it is very important for them to be able to judge distances with their eyes, so that, when the moment comes to pounce, they pounce right *on* the prey – and not behind it or in front of it.

The monkey's two-eyed stereoscopic sight is the nearest among animals to the human being's. When you think of a monkey's habits, you can see that the power of focusing both eyes on one object is of great use here. The animal picks things up with its hands, just as a man does, and so it has to know a lot about shapes: and to be able to judge distance accurately is most important to a creature that has to leap from one branch to another among the high tree-tops.

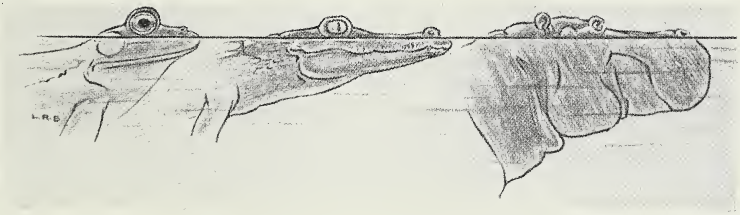
The position of the eyes may also be influenced by the habit of living in the water. Look at the picture of the heads of a frog, a crocodile and a hippopotamus. These three animals are very unlike one another in many ways; but they are similar in being vertebrates with lungs, who live under water most of the time but must somehow get air to breathe. You notice that they all have sticking-out eyes near the *tops* of their heads: and their nostrils are at the very tip of the snout. Now you can see that if the frog and the crocodile and the hippopotamus have bulging eyes on the tops of their heads, they can keep their bodies quite below water, and just stick out their eyes above the surface to see what is going on, and the tips of their noses to get air for their lungs. In this way the frog is safely hidden in the water from the bird that might come along and gobble it up.

And the crocodile can lie hidden while he patiently waits for a thirsty deer to come down and take a drink. From his watery hiding-place the concealed reptile then suddenly comes to the surface and snaps the unfortunate deer with his terrible jaws.

Photo, H. Bastin

Head of a monkey.

Birds have a more wonderful sense of sight than any other animal. A bird's eye is certainly its best sense-organ. When we want to say of some person that he has very keen eye-sight, we say, 'He has the eye of a hawk.' Not only are birds able to see clearly for enormous distances; but their sharp eyes spy out every tiny movement, and they have extraordinary powers of focusing. No animal's sight is so piercing and keen as a bird's.



Drawn by L. R. Brightwell

The position of eyes and nostrils in animals that spend much time under water.

From Wells, Huxley and Wells' *The Science of Life* (Cassell & Co. Ltd.)

In all the mammals, the focusing is done mainly by changing the shape of the lens, just as we do. But some animals have not this power, and, since the shape of their lens cannot be altered, they have to manage some other way when they want to get things into sharper focus. In fact, most of them do what we do with a good camera or with a magic-lantern, and push the lens itself back and forth, using muscles, however, where the photographer or the magic-lantern man would use a screw. When a frog wants to see things near at hand, he pushes forward the front part of the eye with the lens in it, so that the eye seems to pop a little farther out of his head. Then when he is looking more into the distance again, his eye sinks back to its original position in the socket, so that the lens is nearer to the retina. With most fishes, it is the opposite way. Seeing distant things under water is pretty difficult, so the eye of these completely under-water animals is set for near-by things, instead of for distance as with us and the other animals that live on land. When a fish like a cod wants to look into the distance, it has to make a special effort, and it draws its *lens* back a little by means of a muscle cord inside the eye, so that it comes nearer to the retina. But a shark cannot do anything about focusing at all unless it moves its whole body: a shark has to swim nearer to a thing if it wants to see it more clearly. That makes one think of the cheap camera state of affairs.

Then, about the power to see colours. Birds seem to have a good colour sense; and that is rather what you might expect, since they are so often gaily coloured themselves and probably recognise their friends and their enemies by colour as well as by form. And a colour sense must be very useful to creatures like birds, which feed a lot on fruits. Monkeys also have a colour sense; though whether they see colours just as we do, there is no knowing. . . . Experiment seems to show, however, that some of the mammals are colour-blind. The dog, for instance. To us it seems rather sad, perhaps, to think that the dog lives in such a grey, photograph world. And it is not much consolation to know that the dog is far better than we are at distinguishing between dark shades of grey, or even of black. Just as the dog's ear is far quicker than a man's at detecting very slight changes in rhythm, so also is his eye far better able to distinguish between fine shades in his colourless surroundings. You must remember, however, that for an animal with such a marvellous nose and such keen hearing, the sense of sight does not count for so much as it does with us. If the dog knew how feeble our sense of smell is, he would probably think that *we* were the ones to be pitied for losing so much of the pleasure of the world.

CHAPTER XXVIII

HOW ANIMALS LOOK AT THE WORLD (ii)

'SEEING' LIGHT AND GETTING PICTURES – THE SNAIL'S HORNS AGAIN – THE EARTHWORM HAS NO EYES BUT IS SENSITIVE TO LIGHT – THE SHORT-SIGHTED CATERPILLAR – THE BUTTERFLY IS GOOD AT SEEING BUT CANNOT FOCUS – TO SHOW THAT A BEE CAN TELL ONE COLOUR FROM ANOTHER – THE INSECT'S EYE IS A LATTICE WINDOW

ALL these creatures of which I have been telling you have eyes not so very unlike your eyes and mine. Their eyes are much the same shape as ours and have the same chief parts; and – there are always just two of them.

But now we come on to the animals made on a different pattern from the backboned pattern, the very small animals about which we know far less than we do about our friends the cat and the dog and the horse. We watch the fly and the snail, and we learn what we can of their habits by observing what they do; but we shall never really know for certain what the world looks like to them. We have to do a lot more guessing here.

One reason why we cannot know for certain what the world looks like to an insect is because the eye of an insect is made on quite a different plan from our eye. And another reason is that the insect's brain, which gets the messages from the eye, is quite different from our brain and from the brains of other vertebrates. The eyes are different and the brain is different.

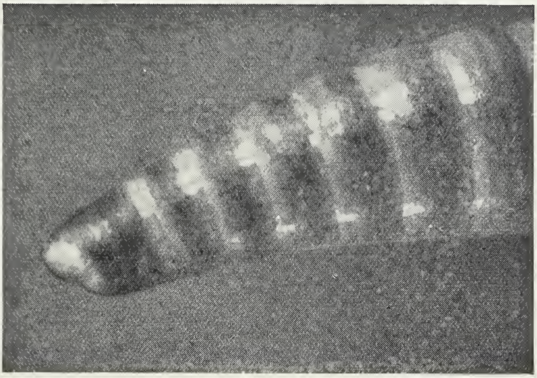
Before I go on to speak about the eyes of these small animals, like insects and snails, I want you to remember that the eye does two things for us. First of all, it gives the feeling of light. And then it also gives pictures. The picture-seeing part cannot happen without the light-seeing part. But the first, the light-seeing part, can happen without the picture part. In the morning, the sunlight comes in through your window and strikes on your closed eyes: your eyes send a message to your brain that there is light, and you wake up. Then you open your eyes, and now you get pictures: you see the window and the curtains and all the rest.

Bear this in mind, because it will help you to understand better what the eyes of many of the small creatures do for them. Look back at the picture of the snail on p. 53. The animal has put out its horns, its feelers. There are two pairs, as you see; a long pair above and a shorter pair below. The snail's horns are for touching things, and perhaps for smelling out its food; but at the ends of the long pair there are also eyes – one tiny black speck of an eye at the tip of each of the long feelers. If you gently touch the snail's horn, the snail draws it right back into its head, and the eye disappears from view. Then presently the snail slowly stretches out its horn again, with the black eye-spot at its tip. Now, from the structure of that eye, I think that probably the snail does not see shapes clearly. It probably does not get much of a picture, except of things very, very close to it, and even then rather blurred. But the snail's eye is very good for distinguishing light from darkness.

Some of the small animals are sensitive to light even though they have no eyes at all. Opposite is an enlarged photograph of an earthworm's head. Here there are no eyes (those bright spots you see in the photograph are just reflections from its shiny skin). Having no eyes, the earthworm cannot get any pictures of the world. And yet the worm is very sensitive to light. It feels through its whole skin if a bright light is shining on it; it hates this feeling and crawls away as quickly as it can into a dark place. You can easily understand why it dislikes the light so much, for to have light shining on it means that it must be above ground during the day, and so in danger of being spied out by some hungry bird. For the worm, then, light is a danger sign. So it is very useful for the creature to be sensitive in this way. But real eyes would be useless to an animal that spends practically the whole of its life underground and comes to the surface willingly only after dark. If the worm does get to the surface in the day-time, it is quite by mistake; and the sooner it hurries back into the dark earth, the safer it will be.

A caterpillar has no less than fourteen eyes, seven on each side of its head. But these tiny eyes of the caterpillar are chiefly useful for telling it about light. The caterpillar has to know where the light is coming from, because the green plants it feeds on grow only in the light. But though it has seven pairs of eyes, the caterpillar probably cannot see the shapes of things that are more than an inch and a half away. Caterpillars are very short-sighted, and they depend mainly on their sense of touch for finding their way about.

But when the caterpillar turns into a butterfly, *then* it really sees. The butterfly's eyes give it pictures, and these pictures are coloured. Nearly all grown-up insects see very well. You know how difficult it is to take a fly or a wasp by surprise. As soon as you get near it with your hand, the insect sees you and is off. The eyes bulge out so much at the sides of the head that they look behind as well as in front. Compared with us, though, insects are very short-sighted, and probably they cannot focus well. A butterfly sees clearly for a distance of three feet, I believe; beyond that, everything is rather blurred. But up to the distance of three feet, the butterfly can see the shapes of things very well indeed. And the eyes of all insects are extraordinarily quick at noticing movements. If you wave a net about, a dragonfly can notice that movement from a distance of twenty yards. The dragonfly cannot see the shape of you or of the net from so far off; but it can see that something is moving, and, as that is a danger-sign, the insect is quick to take the hint, and off it goes.



Photo, H. Bastin

Close-up of an earthworm's head.

In last chapter I said that dogs, and probably many other vertebrates, are colour-blind. But there seems no doubt that bees and butterflies see colours as well as shapes. It is very useful for these insects to be able to tell one colour from another, because they have to go to the flowers for their food, and if the flowers looked just the same colour as the leaves, the animals wouldn't find them nearly so easily.

How can we know that insects like bees and butterflies are able to distinguish one colour from another? Ever so many experiments have been made. I shall describe just one of them, because it is a thing you can try for yourself if you keep bees.

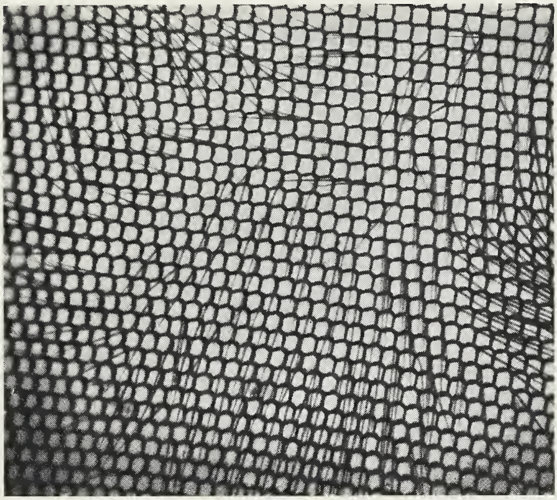
This is what you should do. Cut out squares of brightly coloured paper, all exactly the same size but of different colours – blue and red and green and yellow and white and so on – and put them side by side like a chess-board on the grass near the hive. Now, on one square – any colour will do, but let us say it is to be the yellow one – put a little glass saucer with water and sugar in it. Now wait. The bees will come to drink the sugar-water on the yellow square. When they have finished their meal and gone away, arrange the squares differently, but again put a glass saucer of sugar-water on the yellow one. Now wait again. The bees come and feed. Rearrange your squares once more, and again set your bait. Do this several times: with all these experiments you have to be very patient. Now, the last time you arrange your coloured squares, *don't* put any sugar-water on *any* of the squares. The bees will come again to look for it, and you will find that they will go to the yellow square first, because that is where they expected to find the food. You see, they have picked out the yellow square easily enough from the other colours, although there was no sugar to attract them this time. So clearly they can tell one colour from another.

This little experiment about the yellow square also shows that bees have memory. They remember where the sugar-water was: they have come to associate yellow with food.

It seems that bees especially like blue, and they like yellow. They don't much care about bright red, and probably they are what is called red-blind: to the bee black and scarlet probably look much the same. And when you come to think of it, there are not many scarlet wild-flowers – in this country, anyhow. There are poppies, of course: but you will notice that bees do not visit poppies as a rule. I should think the scarlet poppies look black to a bee.

Now, here is another interesting thing about insects' sense of colour. They can see something where we see nothing but darkness. The colours we can see are the colours of the rainbow. But insects probably see colour beyond the violet edge of the rainbow. The light-waves there are for us just 'ultra-violet,' as I explained on p. 175. But 'ultra-violet' is not for us a colour. It is rather exasperating to think that there are colours we shall never see, and that here some of the tiny animals have an advantage over us. To describe the experiments that have proved to scientific men that insects see these extra colours would take me far too long. I am just mentioning the fact, so that you realise the difference in the bee's point of view: the bee sees a coloured world, but the coloured world of the bee must be a different coloured world from ours.

All this time I have not said a word about what an insect's eye is like: I have just said that it is different from the eye of a vertebrate. These black, shiny things behind the antennæ of the hornet on p. 167 are the eyes. They are pretty big. But some insects have much bigger eyes than a wasp has: look at the house-fly on p. 135. In a dragonfly the eye is as large as the eye of a mouse, and simply gigantic in proportion to the insect's little head.



Photo, John J. Ward

A bit of the surface of a fly's eye, shown very large.

Each of these big eyes is made up of thousands of tiny, tiny eyes packed close together. In a butterfly's eye there may be as many as six thousand. Every one of these tiny eyes has its own lens and its own retina and its own tiny nerve going to the butterfly's brain. The picture above shows the surface of a fly's eye – enormously enlarged, of course. It looks like a very fine network. Each space in the network is really the surface of one of the tiny eyes. They are all set close together, like stones in a pavement, and each has a sort of six-sided shape.

People have often puzzled very much to know how these insect eyes work. What does the world look like to an animal that sees with such a complicated sort of eye ? Does each little eye see the whole of the picture for itself ? Or does each little eye see just a scrap of the whole picture ? Here's another way of explaining what I mean by that. You know those puzzle-blocks, made of cubes of wood with bits of pictures pasted on them ? And you know how you have to fit these blocks together in order to copy the whole picture. Let's pretend it is a picture of a ship on the sea. Does each tiny eye see the whole ship and the sea and the sky ? Or, does one little eye correspond to just one block in the puzzle and see just a tiny bit of the sails, for instance, or just the captain on the bridge, or just the flag at the mast-head, or just a bit of a wave ? And does the fly get the entire picture because each of its tiny eyes receives and passes on to the brain just its own tiny share of the whole, like the puzzle-blocks when they are put together properly ? . . . That seems to be the truth. I'll put it another way. Looking out through our eye is like seeing the world through a plate-glass window with one big pane: looking out through an insect's eye may be more like seeing the world through a lattice-window made of small six-sided panes of glass.

CHAPTER XXIX

BRAIN AND NERVES

RESPONSE TO STIMULUS – THE NERVOUS SYSTEM CONSIDERED AS A TELEPHONE SERVICE – THE CENTRAL EXCHANGE – CO-ORDINATION AND CONTROL – THE CHIEF PARTS OF THE BRAIN – MAPPING OUT THE CEREBRUM – HOW THE SURFACE IS INCREASED – WHERE MAN IS INFERIOR TO OTHER ANIMALS – AND WHERE HE IS THEIR SUPERIOR

IF somebody flashes a strong light in front of your eye, the pupil of your eye gets smaller and your eyelids close: if you sit by mistake on a tin-tack, you get up hurriedly: if the engine of a car back-fires, you jump, and perhaps you involuntarily put your hands over your ears to shut out the horrid noise: if you go into a baker's shop where there is a good smell of newly baked bread, the chances are that your mouth will water.

In every one of these events, some part or other of your body has made a response to a stimulus from outside, a stimulus that has reached a sense-organ. In the first one, the eye was the sense-organ, and the stimulus came in the form of powerful light-waves: in the second, the skin was the sense-organ, and, in answer to the message from a pain-spot in the skin, you got up as quickly as you could: with the loud noise, the sense-organ was your ear, and it was stimulated by sound-waves in the air: when you went into the baker's shop, the patches at the top of your nose were stimulated by tiny, good-smelling particles that came in with your breath from the air outside.

Now your body is pretty big in proportion to these various sense-organs, and the part of your body that answers the message of the stimulus may be some distance from the part through which the message came in. Your ear is quite a long way from your trunk and your arms, yet the muscles in your trunk and arms came into quick working almost immediately after your ear-drums were struck by the loud sound-waves. Has it ever occurred to you to wonder how the message gets from your ears to the muscles that move your trunk and limbs ?

Inside your body, and inside the bodies of all the animals we are concerned with in this book, there is a very elaborate arrangement of white threads, called nerves, which link up one part with another. And it is along these that messages pass to and fro in the body. It is like a sort of telephone system between one part of a town and another, setting all the districts in easy communication. The comparison with a telephone system is not so very far-fetched; for it seems that the messages that go along the nerves are transmitted electrically.

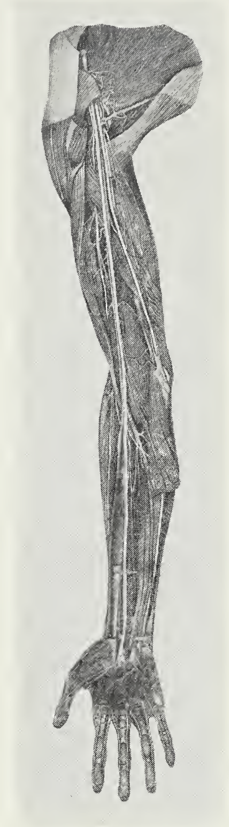
By telephone you cannot communicate directly with a friend's house. If you have many friends living in different districts and you want to talk with them all by telephone, it would be too complicated if you had to have a separate wire from your house to each of theirs. The air would be all full of interlacing wires and there would be a terrible mix-up. What you do is to get through to a telephone exchange, and, at the telephone exchange, your line is connected up for the time-being with the telephone of the particular person you want to speak to; at the end of the talk, you are disconnected, and then you can get through again to the exchange and talk to someone else. So also it is in the nervous system of the body. The nerve that goes from your ear does not go straight to the hand that is raised to shut out the horrid noise of the back-firing car. For, if that were the plan, the ear should also be connected up with hundreds of other muscles in different parts of your body. So the telephone-exchange idea is brought in. And what happens is that the nerves from the sense-organs all run in to the central exchange, and then, in the central exchange, connections are made with astonishing rapidity to just those other nerves that will take the message to the particular part that is to act in response. For instance, the message to the exchange comes in, 'There is a terrible noise, so loud that it seems as though it would break the ear-drum'; and then a message goes out from the exchange along another line to the arm saying, in effect, 'Contract such and such muscles, so that the hand is lifted and covers the ear to shut out the worst of the noise.' That sounds very slow and elaborate, but actually it all happens in a flash: nervous messages pass along the nerves at a terrific speed – 400 feet a second – and the exchange is amazingly good at the linking-up job.

The body's nervous telephone exchange is what we know as the 'central nervous system,' and it consists of the brain and the spinal cord. The brain lies in the head, and from the brain the spinal cord runs along your back from end to end. Without this central nervous system, your life would be impossible. It regulates and controls all your body does. And because it is so precious, it is very carefully protected from harm within the skull and backbone. When a man breaks his neck, he dies – not because he breaks his backbone, but because he breaks part of his central nervous system.

The stuff of which the brain and spinal cord are made is the same sort of stuff as the nerves and their endings are made of; and a great deal of it is formed of nerve-threads that come in from the sense-organs or are going out to the muscles and other parts to tell them what to do next. And between those that come in and those that go out are other nerve-threads, running in the length of the cord and brain, and linking up the parts at different levels. When you think how complicated the structure of the body really is, and how you have to move quite a number of different muscles in order to perform even a simple action like raising your hand to your ear, it is astonishing that the system works so smoothly and that mistakes are so seldom made.

The central nervous system not only links up the incoming messages with the outgoing messages. It acts as a control over the whole of the body's working. No part of the body is allowed to act on its own, or without regard to the other parts, for that would lead to great confusion. The central nervous system sees to it that each part works in connection with a common plan which is for the good of the whole body.

And remember that it is not only the outer parts, like limbs or eyelids or lips, that are to be kept in communication and controlled. There are all the inside parts as well, about the working of which we are seldom conscious unless things go wrong. The movements of your stomach in digestion, for instance, and the manufacture of the digestive juice: the movements that your chest and diaphragm have to make in breathing: the beating of the heart, on which your whole existence depends – these things and many others are



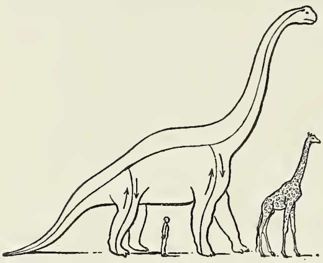
After Rüdinger

Some of the nerves of the human arm: muscles and tendons can also be seen.

From Hill's *Living Machinery* (G Bell & Sons, Ltd.)

managed for you and controlled by the nervous system, without your ever having to think about it at all and generally without your even knowing what is happening.

Now you know, from what I have already said, that there are two sorts of actions going on in the body – firstly, those of which we are conscious and with which we can deliberately interfere; and secondly, those that go on all the time without our noticing them much and without our being able to control them. The movements of the stomach and intestines, for instance, are managed for us by nerves over which we have no control. But of movements that are 'conscious,' movements that we can perform or not as we choose, the brain can take charge: and the spinal cord has then to send such outgoing messages as the brain directs.



Drawn by L. R. Brightwell

The extinct reptile called Branchiosaurus stood 18 feet at the shoulder. To get from the touch organs in its foot, a nerve message would have to travel about 30 feet. The man and the giraffe are put in to show the scale.

From Andrade and Huxley's *Science and Life* (Basil Blackwell)

Let us suppose that you pick up a plate of soup. The plate is unexpectedly hot, and a message about this uncomfortable heat comes in to the central nervous system from the skin of your hands. Your impulse is to drop the plate immediately, lest you be hurt. 'Drop the plate' is the message that naturally would go out from your central nervous system along the nerves to the muscles of your hands. But before that message goes out, there may just be time for you to think very quickly, 'If I drop the plate it may break, the soup will be wasted, and anyhow there will be a frightful mess on the carpet. I shall be scolded and perhaps punished.' It is with the brain part of your central nervous system that you measure these consequences of following your natural impulse: and your brain, having decided that it is better for you to be rather uncomfortable for a few more seconds than to be let in for a scolding or worse, sends out a very different order commanding the muscles of your hands to hold on to the plate a little longer: at the same time a message goes to the muscles of your legs to run you quickly to the nearest table!

Wherever there is a well-developed brain, such as a human being possesses, a certain amount of what the body does ceases to be automatic; the living being then has choice of action, and by means of his brain he can decide what the rest of his body is to do. There are always certain things that remain out of our control, as I said; it might be really dangerous for the body if the brain could interfere with the beating of the heart, for instance. These absolutely necessary actions go on all the time automatically – without any willing and without our having any choice.

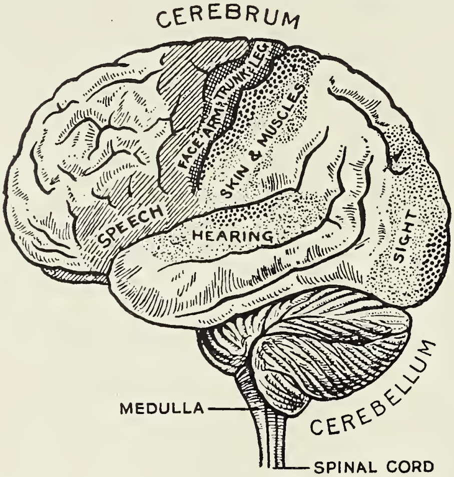
(Perhaps you will say that you *can* control your breathing. And you can, up to a certain point. But only up to the point that is not dangerous for your body. If you try to hold your breath, you will soon find that the longing for air gets too much for you: in spite of yourself, you give in and allow your muscles to make your chest and diaphragm work, as the presence of too much carbon dioxide in your blood is stimulating your central nervous system to let them do.)

But the brain can control all the things that are not absolutely necessary for the carrying on of your life. And it is with the brain that you do your enjoying of what is beautiful and good, and your hating of what is bad: and it is with the brain that you do all your thinking. The brain is a most extraordinary organ, and, as you might expect, it is extremely elaborate in the details of its arrangement, especially inside. But there are only three parts that I want you to notice specially. These three parts are called the big brain (or cerebrum), the little brain (or cerebellum) and the medulla. You see these three parts marked in the side-view picture of the man's brain: the cerebrum is in front, the cerebellum is behind that, and the medulla farther back still. These parts all lie safely inside the skull, and the medulla joins on to the spinal cord, which, as I explained, passes right down the back. The medulla does a lot of controlling, but we do not feel or think with that part of the brain. Nor do we feel or think with the cerebellum: the cerebellum's work is mainly to keep our muscles working in sympathy with one another, and to get messages from the balancing parts of our ears, and to direct the muscles how to work in order to prevent our bodies from toppling over.

It is with the big brain, the cerebrum, that we do all our feeling and thinking. And this is the part that can take control of so much of our actions and order the other parts to do as the person wishes. Different parts of the cerebrum take charge of different shares in this control. In that picture you will notice words printed on the cerebrum: at the back, for instance, is the word 'sight,' and this means that to the back part of the cerebrum come in all the messages from the organs of sight, the eyes:

another part is marked 'hearing,' and that is the part where the sound-messages from the ears are appreciated: speech is controlled from yet another patch of the cerebrum: and so on with all the rest.

Perhaps you wonder how it is that we know which part of the cerebrum deals with hearing, and which with speech, and which with some other thing. I shall give an example to show you. Suppose a man has some bad accident to his head and goes deaf in one ear. The doctor examines his ear to see if the ear has been damaged. But perhaps the ear is all right; the drum is not broken and the little ear-bones are in their usual order: nothing wrong with the ear. Yet the man cannot hear with it. The doctor has the man's head radiographed. And then he sees from the picture that in the accident the bony wall of the man's skull was broken, and a bit of broken bone is pressing against the brain just where the word 'hearing' is printed in the picture. He then gives the man an anæsthetic and lifts up the bit of broken bone so that it no longer presses on the hearing part of the brain; and the skull mends nicely. When the pressure on the brain is removed by that operation, the man hears again all right with the ear that wasn't working. If the break in the skull occurred at some other place, it would be some other part of the man's body that would be thrown out of action. If the pressure were at the



Drawn by L. R. Brightwell

Left side of the human brain.

From Wells, Huxley and Wells' *The Science of Life* (Cassell & Co., Ltd.)

back of the cerebrum, for instance, he might go blind for a time, although his eyes were quite undamaged.

Now this example shows two things. First it shows that the cerebrum *is* all mapped out into regions, each of which has to do with some special kind of business in the body. And then it shows that it is not the sense-organs themselves which see and hear and taste and smell, but the brain that gets the messages from them. The sense-organs just receive the messages and send them on by the nerves. It is the brain that 'makes sense' of the messages as these come in to it. We really see and hear with our brains, just like the cat on p. 140 – and not with our eyes and ears.

Notice yet another thing about the cerebrum. Its surface is all folded and crinkly. The idea of this is to make the surface of the cerebrum as large as possible in relation to its size. The surface of the cerebrum is very important, for there lie the ends of the nerve-threads and the little parts that make the telephone-exchange connections. The more surface there is, the more of these you can fit in. The skull which encloses the brain must not be too big, however: if one's skull got too huge, it would be impossible to hold up one's head. But you can increase the surface of the brain in another way: and that is by folding and crinkling the surface so that this is very large in proportion to the bulk.

Wherever, then, you have a crinkly cerebrum, this means that there is plenty of surface for extra switch-boards in the telephone exchange. And the more switch-boards there are, the more extraordinary may the brain's power become. The living being in whose head lies this large crinkly brain, becomes better and better able to appreciate the world around him and to get the very most out of his life by managing his body; and, through his body's actions, he can manage also the things that lie outside him altogether.

It is here that human beings are so different from other living things. They are able, if they choose, to control their actions as no other creature can; and deliberately to control, through their actions, the fate of other beings. And they owe all this to having such a marvellously developed brain. In no other creature do you get a brain with such a huge, crinkly cerebrum in proportion to the body's size. Compared with other animals, a human being is in many ways inferior. He is very weak and defenceless compared with a lion or a tiger, for instance: he is very slow in movement compared with a horse or a deer: by flapping his fore-limbs a man cannot rise off the ground and move about in the air in the way a bird can:

his senses are feeble compared with those of any cat: he has no fur or feathers to keep out the cold, nor any natural armour such as insects or tortoises have. Yet his brain makes it possible for him to get over all these disadvantages: in his cerebrum, a man is so superior to all other living creatures that he can control their fate as well as his own. To make up for lack of strength and for lack of great teeth and claws, man can invent and manufacture weapons that are far more deadly: to make up for having no fur or feathers, man can invent clothes to keep his body warm: to make up for having no wings, he can invent balloons and aeroplanes: to make up for having no natural armour, he can make himself helmets and breast-plates and shields of metal. So he can have all the advantages of all the animals together. And far more than that. Man has invented reading and writing. And this gives him the power of setting down what he has experienced and thought about, so that it is not lost when he dies. For what one man writes, those who come after him can read and profit by – if they choose !

CHAPTER XXX

ANIMAL BEHAVIOUR

SIX BRAINS COMPARED – THE SAME PARTS BUT THE PROPORTIONS DIFFERENT – THE NERVOUS SYSTEM OF AN EARTHWORM – STUDY BEHAVIOUR – PRACTICE MAKES PERFECT – KNOWING WITHOUT LEARNING – INTELLIGENT AND INSTINCTIVE BEHAVIOUR – THE MONKEY DEALING WITH A NEW PROBLEM – COMPARE A DOG'S BEHAVIOUR WITH A HEN'S

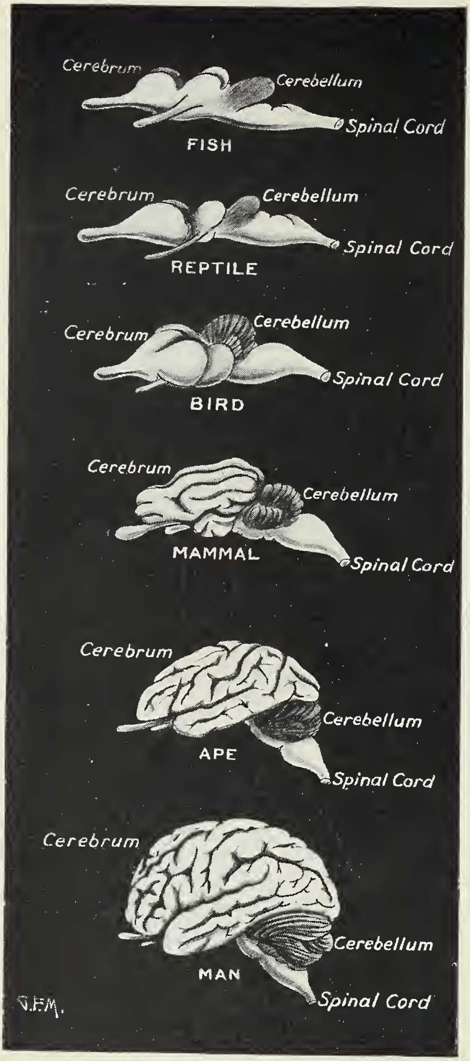
DO animals think ?

Honestly, I don't know the answer to that question. Nobody could answer it with certainty. We cannot get inside an animal's body and discover how it feels and how its mind is working: and, if the animal has thoughts, it cannot tell us about them in human language. The best we can do is watch carefully how the animal behaves, and then make guesses as to what may have been in its mind to make it act like that.

I know, of course, that an animal has a brain which controls its actions. And as I believe that I do my thinking with my brain, I suppose the animal, *if* it thinks, thinks with its brain too. So, before we go on to consider how animals behave, let us first of all just compare animals' brains with our own and see if there is any resemblance.

There is a great deal of resemblance. The picture on p. 198 shows six brains in side-view – a man's brain at the bottom and then five animals' brains above it. (Of course the sizes are not correct. The ones at the bottom are drawn very small, so as to get them into the page.) Immediately above the man's brain is an ape's – perhaps a chimpanzee's. Above that is a brain marked 'mammal': I think it is a dog's brain. Then above the dog's brain is the brain of a bird. Higher up still, is one marked 'reptile': probably it is a lizard's. And right at the very top is the brain of a fish.

The thing I want you to notice is that the man and all these very different animals have the same chief parts to the brain. They all have a cerebrum in front, they all have a cerebellum behind: then comes the medulla (though that is not labelled in the picture): and away from the back of each brain goes the spinal cord. Now while it is true that all these brains are arranged on the same sort of plan, what strikes you at once as you look up the row from the bottom to the top ? Isn't it the great difference in *proportion*



Side-views of brains of man and various animals.

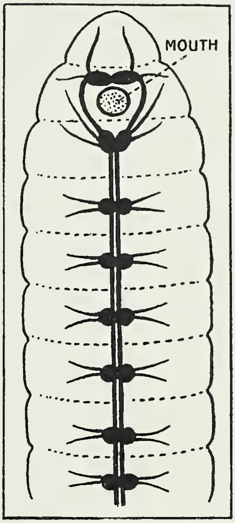
From Thomson's *The Outline of Science* (George Newnes Ltd.)

between the cerebrum and the rest of the brain? The cerebrum is simply enormous in the man's brain. It is smaller in the ape. In the dog it is smaller still. And it gets smaller and smaller as you go up the row, until in the fish it is a very small, pear-shaped thing and quite smooth. Notice the smoothness. For another difference you will find is that the animals near the top have no crinkles on the cerebrum.

In last chapter I said that we do our thinking with the cerebrum. So it seems reasonable to suppose that other creatures with a cerebrum do some thinking too. But where the cerebrum is large in proportion, and crinkly, the animal probably does more thinking than the animal that has a very small, smooth cerebrum. And we actually do find that animals such as monkeys and dogs behave in a way that is more like a human being's way of behaving than a bird's way is, or a fish's.

You will have noticed that all the animals whose brains are shown in that picture are what we call vertebrates. All vertebrates are built on the same plan, as I have explained before; and this shows in the pattern of their brains just as everywhere else in their bodies. But we musn't leave out the invertebrates – the worms and the snails and the insects. These have no backbone: they are built on quite a different plan from us: and when we come to the nervous system in such animals, again we find that this looks very different from our own. On this page there is a very simple drawing – just a sort of a map – to show the way an earthworm's nervous system is arranged.

Instead of having the main part of its nervous system along its back as we and the other vertebrates have, the earthworm (or the insect, for that matter) has it on the under side of its body, a little way below the skin. In that picture, the worm's back and its alimentary canal have been taken away, and we are looking into its inside: the nervous system is drawn in black. Just in front of the circle marked 'mouth' there is a sort of double knot lying in the worm's head. That double knot is the earthworm's brain. It is very tiny, even when you think of it in relation to the animal's size: but, tiny though it is, it seems to do all that the earthworm requires of it. What interests me at the moment more than its small size, is that it does not show the parts that you would find in the brain of a vertebrate animal. Even if you magnified it enormously, you would not find a cerebrum and cerebellum. In fact, the brain of an earthworm is so utterly unlike our own that it is quite impossible to guess, from just looking at the nervous system, whether an earthworm thinks.



Drawn by L. R. Brightwell

Nervous system of a worm. From a nerve-ring round the mouth a double cord runs down the under side of the body with swellings on it. The 'brain' is the double knot in front of the mouth.

From Wells, Huxley and Wells' *Science of Life* (Cassell & Co., Ltd.)

But, as I said at the beginning of this chapter, there is another way to study the question of animals' minds; and it is a much better way than dissecting their dead bodies and looking at their brains. The thing really to do is to watch very carefully how living animals behave, and then compare their behaviour with what our own would be in the circumstances. That may sometimes give us a clue to what is passing in their minds.

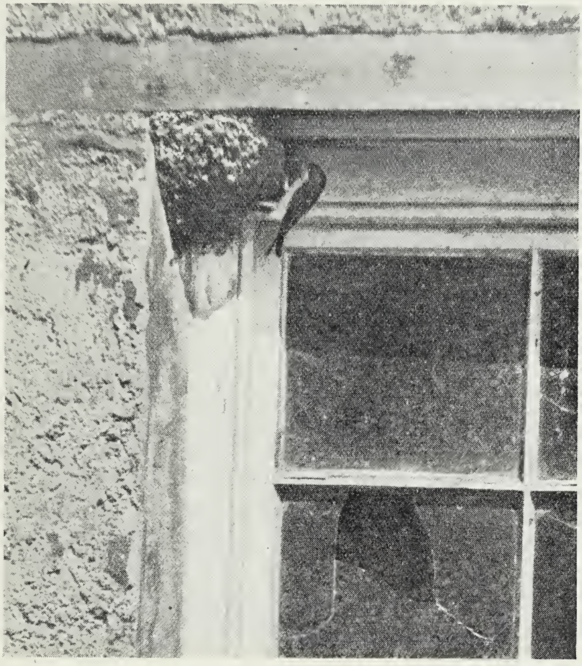
When you were a baby, you had practically everything to learn. Things were very difficult for you at first that now you do without thinking about them. You knew from the moment you were born how to use your mouth for sucking up milk; but you knew very little else of how to do those actions that require carefully controlled muscular movements. You had to learn almost all of that by slow degrees. You had to learn to walk; and it was a slow and difficult business. You had to learn to talk; and it was quite a while before anyone but your father and mother understood what you were trying to say. Then you had to learn to use a spoon and fork, and how to read and write: now you are still learning new things almost every day, and how to do them better and better. A human being hardly ever does a new kind of thing quite right the first time: we do it imperfectly at first and with some effort. Only gradually, with plenty of practice, do we come to perfection. But there is almost no limit to what we may learn to do, if we devote enough time and trouble to it.

Now compare a young bird with a baby. The bird also has to learn some things: it has to learn to fly, for instance. That takes some practice: the father and mother bird give the young one lessons and help it. But after a very short time indeed, the bird comes to the end of its learning. Indeed, it can do many of the most difficult things without ever having been taught, and, what is just as extraordinary, it does them quite perfectly the first time it tries.

Let me give you an example. You know the swallow that we call the house-martin? When the spring comes, the birds that were born the summer before are quite grown-up and ready to marry. The male swallow chooses a wife and they begin to make a nest for the children they are going to have. Now remember that these young birds have never even seen a nest being made. They sat in a nest when they were babies; but it was all there when they arrived, and their parents never showed them how the work should be done. But though they have never had a lesson and though they have nothing to imitate, the swallows proceed now to make a perfect one. And before making it, they choose just the right place. This kind of bird does not make its nest in a bush as a thrush would, nor on the ground like a lark: the right place for a house-martin's nest is under the eaves of a house. Nor do house-martins build the nest of sticks and moss: they build it of pellets of mud. Very difficult to do all this, you would think, without any pattern and with no one more experienced to help you. But the house-martin seems to find no difficulty, and it makes as perfect a nest of the house-martin kind as its parents did the year before.

I chose the house-martin as an example; but any sort of bird would do. They all know, of themselves, what is the right place for their kind of nest, and they make the kind of nest their parents made, whatever that may be.

Then, when the end of the summer is near, the swallows fly away to warm countries for the winter. They all go. And the new brood, hatched out this very season, often travel by themselves; for it is quite usual for them to set off before their parents do. Think of what that means. These new young swallows have never been out of the little patch of England where they were born. Yet they fly off to Africa – without a map or compass, and without any older birds to show them the way. And they get there all right. Even if he had wings and could fly, a man couldn't do a thing like that. A human being, setting off like that without guidance, would get lost at once. But the birds somehow know within themselves just what to do and when to do it; and few of them go really astray, even on their first journey of hundreds and hundreds of miles across the wide sea and over foreign lands.



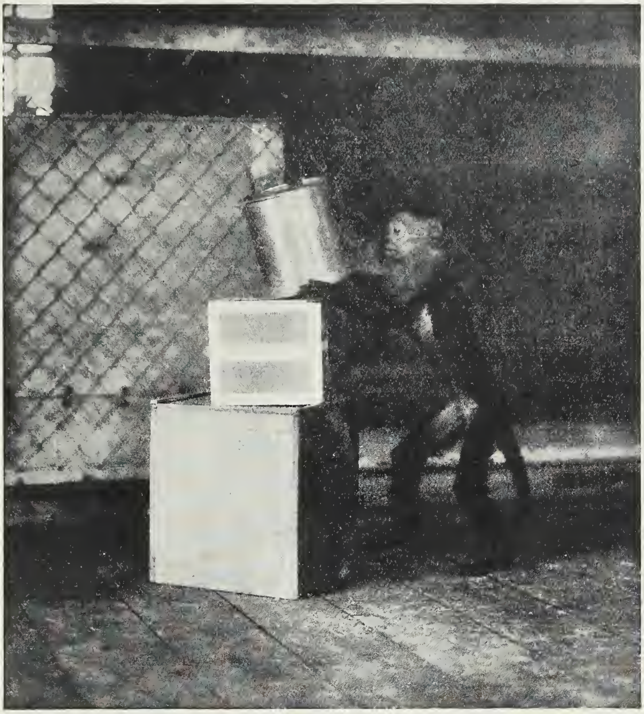
Photo, Peter Webster

House-martin building its nest of mud.

We give different names to these two sorts of behaviour – the baby's on the one hand and the bird's on the other. We say that a creature like a human being, who only gradually learns to do a thing, is the kind that is able to behave *intelligently*. Creatures that are intelligent are able to learn new things, and – this is important – they can devise ways out of difficulties that they have never met with before and that their parents have never had to face. In contrast to this we have what is called *instinctive* behaviour. The instinctive creature does from the beginning, and without having to be taught, all that is necessary for the life of its kind. At coping with the normal difficulties that come their way, the purely instinctive animals are simply amazing. When I deal with bees in a later chapter, I shall be giving you a very good example of what instinctive behaviour may lead to. But although there are many advantages in instinctive behaviour, there is this great disadvantage – the animal is not much good at doing anything different from what it and its parents have been accustomed to do: if it is faced with an unusual difficulty, it can't think out a way of getting over it.

Now of course you have noticed that the baby's behaviour is not all pure intelligence, by any means ! It knows how to suck milk from the beginning, without being taught: in that way, a baby's behaviour is as instinctive as any bird's. And there are other ways too in which a human being's behaviour is instinctive. But, on the whole, a human being is much more a creature of intelligence than of instinct. Nor is the bird purely a creature of instinct. It does some learning from experience when it learns to fly. And we have all had pet birds that were able to learn new things. I'm not talking about the tricks we teach the bird to do. What I mean is that some birds are capable of making discoveries and of finding a way out of new difficulties. We had a parrot, for instance, who discovered quite by himself how to undo the latch of his cage and hold the door open with his foot so that he could come out when he liked and fly about the room. You may be sure that no one had ever taught the bird this most inconvenient trick; and it was a thing parrots would never have to do in the forests of the Amazon, where he came from. No, the parrot, although mainly a creature of instinct like other birds, was acting intelligently there: he had to practise a bit before he found out the solution to his problem of escape, and I feel sure he did some sort of thinking before he worked out the plan in his mind.

Generally speaking, though, it is the animals with the big, crinkly cerebrum that are the most intelligent. They are the best at dealing with a new or out-of-the-way situation. I shall give you an example. On this page you see a photograph of a monkey, whom I shall call Jacko. Jacko was a pet monkey who lived in a very big, high cage and like all of his kind, he loved fruit; and he especially adored bananas. His master wanted to see what Jacko would do if he were set a new problem. So he tied a bunch of bananas to the top of the cage, hanging into it, but quite out of the monkey's reach. And he left a few old boxes and tins lying about in a corner of the cage. Jacko looked longingly at the bananas, and his mouth watered. He stretched up his long arms, but even they were too short to reach the fruit. He tried jumping up to it, but he couldn't



By courtesy of Dr. Bierens de Haan

A monkey piling up boxes in order to get at bananas which are hanging from the top of his cage. This is quite his own idea.

From Russell's *Behaviour of Animals* (Edward Arnold & Co.)

jump high enough. Then he sat down very sadly, looking most worried. While he sat there, he suddenly spied the boxes in the corner. He looked at them for a minute: then all at once his expression changed; his face lit up with a bright idea. He went and took a box and placed it under the bananas, and stood on it. Still he couldn't reach them. He thought again. And then actually he went and fetched first another box and then a tin, and built them up into a sort of tower. Then he climbed on top of the tower he had made, and easily got the bananas, of course; and he carried them away and ate them in triumph. Now, that monkey was really intelligent. This was a difficulty he had never met with before, and might never meet with again. And I'm sure he *thought* out the best way to solve the problem. Anyhow, a man couldn't have thought out anything better in the circumstances.

Everyone who has a cat or a dog for a friend will tell you stories of their intelligent behaviour. I believe a dog trying to get a bit of meat would have shown as much intelligence as that monkey, if it weren't that paws and teeth are such a poor substitute for hands when it comes to building up a heap of boxes. You can measure the intelligence of a dog against that of a hen if you try the following experiment. Get some wire netting and arrange it to make a fairly long passage-way, closed at one end: be sure it is firmly fixed to the ground. Just outside the closed end put a dish of corn. Then put a hen into the run so that she can see the food, but cannot get at it because of the netting. She will keep on trying to get through the wire: she can think of nothing but what she sees and what seems to her the shortest cut to it, and however often she fails to get through, she goes on doing the same thing over and over again. But now put a piece of meat in place of the dish of corn, and put your dog into the run instead of the hen. Unless he is quite a puppy, he will soon turn and run back along the passage to the open end, and then round the corner to get the meat. He has 'understood' how to solve the problem in the only possible way: he sees almost at once that the short cut is no good really, and that he has to turn his back on what he wants if he is ultimately to get it. This takes intelligence.

CHAPTER XXXI

HOW ANIMALS HIDE

ESCAPE – THE BATTLE IS NOT ALWAYS TO THE STRONG – MATCHING THE BACKGROUND – THE VALUE OF KEEPING STILL – PRETENDING TO BE DEAD – CAMOUFLAGE – SOME INSECT DISGUISES – STICK AND LEAF INSECTS

SUPPOSING you were a wild animal, and a lion were after you – what would you do? You might fight the lion and kill him, instead of his killing you. But you could do that only if you were pretty big and very strong and had sharp teeth and claws, or horns like a buffalo. Or, if you weren't strong enough to fight the lion, you might run away. Lots of animals do depend just on that for safety – on being able to run faster than the creatures that try to catch them.

But supposing you couldn't run faster than your enemy? You might dash into the thick undergrowth or up a tree where he could not follow you. Or you might have a burrow, as the rabbit has; and you could rush into it for safety, leaving your dog enemy outside, panting and barking with disappointment because he was too big to get in after you. If you couldn't fight, and if you couldn't run fast enough, your best way certainly would be to hide.

But it may be that the burrow is some distance away; or there may not be a tree handy to climb. The animal we are imagining has no shelter and its enemy is coming along. The enemy does not see our animal yet; but any moment he may. What is the poor creature to do? Well, what would *you* do in the circumstances?

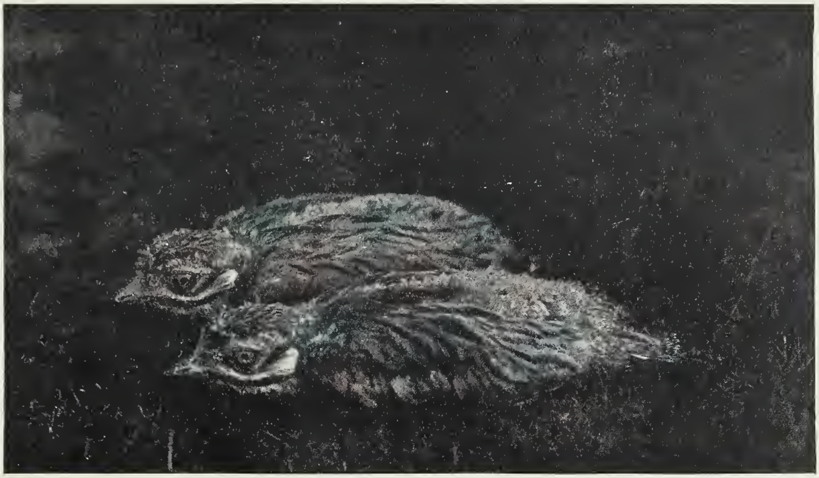
If you were wise, you would either lie flat on the ground, or you would flatten yourself against a wall; and you would keep perfectly still. Now supposing it was a grey stone wall, and supposing your clothes were exactly the same shade of grey – your coat, your stockings, your hat – all grey, just the colour of the wall; then there would be a still better chance that the enemy might pass you without seeing you. Of course, your face and hands would still show up, pinky-white; and that might catch the sharp eye of your enemy, and he might dash after you. But supposing you had a grey face and were wearing grey gloves: that would be better still. Of course, we don't have grey faces. But animals may, because their faces are covered with feathers or with fur. And wearing a covering of fur or feathers to match the background is one of the favourite tricks animals use for hiding from their enemies or for concealment while they lie in wait for their prey.

It was a long time before any people but hunters thought of imitating animals in this way. In the olden days, soldiers went into battle wearing bright scarlet coats: and this really was silly, for the eyes of the enemy could so easily see the red colour against the grass and the trees or the sand. But nowadays soldiers going into battle wear a uniform that is difficult to see from a distance. British and American soldiers wear khaki, because that is something like the colour of the ground: and German soldiers in 1914 wore what is called 'field-grey': and Italian soldiers wear grey-green. But animals had adopted colour-disguise ages before human beings saw the value of it.

When a herd of deer is standing quite still among the bracken or in the shade of trees, you may easily pass them unnoticed, because their colour matches the dead fern or the tree-trunks so well. And little brown rabbits feeding in the meadow look very like mounds of earth; so long as they keep still, you may even mistake them for mole-hills. If the deer or the rabbit moves, of course, the spell is broken. Tree-trunks don't move; mole-hills don't suddenly get up and go scampering across the grass! It is the stillness *and* the right colour to match things in the background that together make such a good protection.

Animals that are in danger seem to know very well the usefulness of keeping quite still. Some kinds of spider, when you touch them even gently with your finger, do not try to run away, but draw their legs close in to their bodies and lie absolutely still, looking as though they were dead. They are trying to make themselves look as small as possible, in the hope of escaping notice: and the advantage of pretending to be dead is that birds which eat spiders prefer to catch living ones. Most flesh-eating animals are not much interested in dead prey.

Birds are so alert and they can fly so fast, that they are not in much danger while they are awake. But their eggs can't fly, and the young birds that hatch from the eggs are often very helpless for a time. The parent birds sit on the eggs and on the young, not only to keep them warm, but also to hide them from enemy animals. Usually it is the mother bird that does most of the sitting: and that may be one reason why the mother bird is often so much dimmer in colouring than is her husband. The father blackbird, for instance, is really black; but the mother blackbird is brown, and not showy at all. And if you come upon a blackbird's nest among the bushes, the mother bird will sit there bravely, quite motionless and not making a sound, in the hope that her stillness and her colour, which is so like the colour of the branches, may prevent your noticing that she is covering the nest where the precious young ones are.



Courtesy of Miss E. L. Turner

Two young stone-curlews crouching motionless when alarmed.

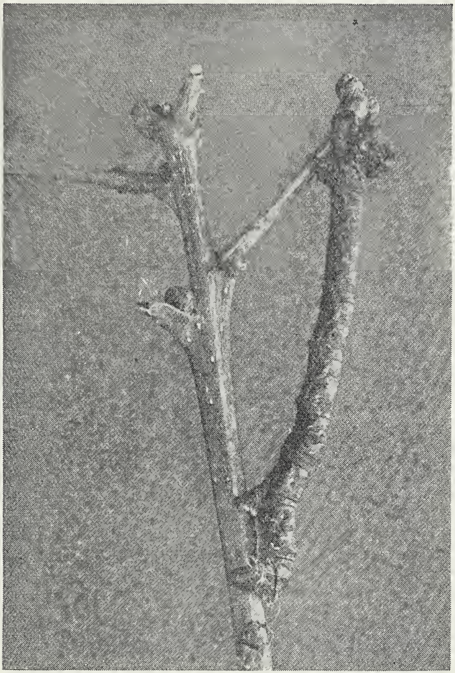
From Turner's *Broadland Birds* (Country Life Ltd.)

Even those young birds that hatch out with feathers on them and with their bodies strong enough to run about and pick up food, are in no little danger from hawks. When the mother partridge warns her chicks that she sees a hawk hovering overhead, they obediently squat down on the ground and remain perfectly still until she gives them the 'all clear' signal. Like the frightened spider, they are trying to make themselves as small and inconspicuous as possible. The hawk is watching for moving things: at that distance, even his sharp eyes cannot see the details, and, if he notices them at all, he thinks the chicks are just little stones, or patches of dried grass on the ground. So presently he sails away to have a hunt somewhere else. The resemblance of such young birds to the ground is helped out by the streaking and striping of their feathery coats. The grass and the ground where they crouch are also streaky – brown and grey and green – and against that background the streaky young birds are even more difficult to see than if they were all green or all brown in tint. I assure you, you may almost tread on a nestful of curlews without even knowing you were near it, so exactly do their coats blend with the background. Some young mammals also have streaked or spotted coats although their parents are of a plain tint. (*See* picture on p. 79; though the background there is not good for the purpose of my argument!)

And usually those birds that lay their eggs in shallow nests in exposed places – curlews and oyster-catchers, for instance – have speckly, streaky eggs of colours that are extraordinarily like the colour of the ground where they lie. If curlews had pure white or red or blue eggs, the hawk would easily see them when the mother got off the nest to stretch her wings; for hawks have a very keen sense of colour. But the spotty, speckly, grey and brown and greenish eggs go unnoticed from a distance.

In the Great War men imitated the animals' tricks for their apparatus as well as for the soldiers' uniforms, and they painted gun-carriages and ammunition-sheds in streaks and patches of green and brown and grey, to hide them from the eyes of the airmen flying in the enemy planes overhead. Ships at sea were also 'camouflaged' in this way. And here it is not merely a question of matching the background colour. You will find, if you make some experiments for yourself, that it is far harder to see the *outline* of a thing from a distance if its surface is painted in differently tinted patches than if it is of a uniform colour all over.

It is not only the vertebrate animals that resort to camouflage. Defenceless invertebrates also use this trick a great deal. Caterpillars, for instance. They are extremely helpless animals and much sought after by sharp-sighted birds. They can't fly: they can't run quickly: they have soft bodies and a thin skin: and they have very bad eyesight. They have to come out to feed on the leaves of plants, right in view of their hunters. Their very slow movements help, no doubt, to prevent the birds' spotting them. But often it is disguise that gives them safety. Opposite, there is a photograph of a small branch with twigs on it, and on the branch is also a caterpillar. Can you see which are twigs and which is caterpillar? . . . It took me some time. If the picture were coloured, you would find that the caterpillar's skin is just the same shade of brown as the branch, and the roughnesses on the skin are exactly like the roughnesses of the bark. Moreover, this particular kind of caterpillar, when it is resting, raises the front part of its body into the air and holds on by the suckers, called 'false feet,' at the hind end. Then it looks more like the twigs alongside it, and there is a very good chance that the bird will miss it altogether.

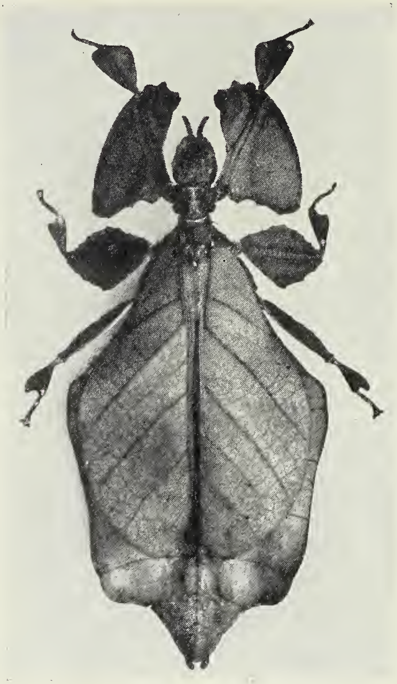


Photo, H. Bastin

Caterpillar of the peppered moth.

It is not only the bark of trees that insects imitate with their skins. Some imitate leaves. On p. 210 is a picture of a most extraordinary insect. It is called the leaf insect. And no wonder! Look at its wings, folded on its back. They are the shape of leaves, and they are marked with what look just like the veins of a leaf. And the insect's legs actually have little frills on them that look like leaflets too. The creature is coloured bright green all over, the colour of a leaf. The leaf-insect does not live in this country: it comes from the tropics. I don't know much about its habits, and I don't know what animals prey on it: but I should judge, from looking at that picture, that the leaf-insect does not fly fast or often. I feel sure it relies for safety on its colour and shape for a disguise; and that its enemies must often pass it by, thinking it is just a part of the plant on which it is standing.

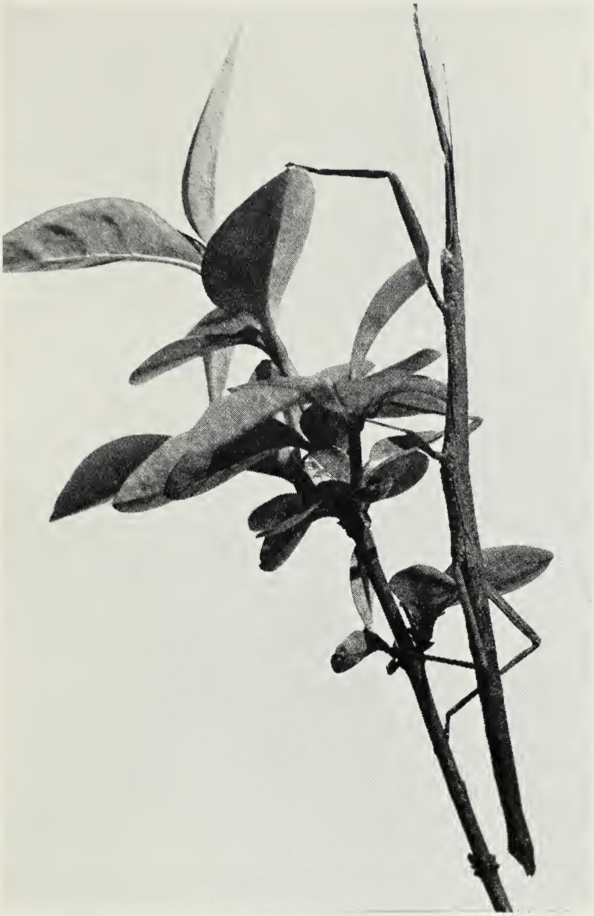
Perhaps you know the stick-insect, though. It is not a British insect, either; but you can buy live stick-insects for a few pence from some of the dealers, and they make very nice pets. For they don't want to move about much, and they are perfectly content so long as you give them plenty of fresh green privet to eat. The photograph opposite shows a stick-insect standing on a twig of privet. It isn't difficult to photograph a stick-insect, because the creature keeps so still for hours at a time. Sometimes it staggers slowly up and down a twig searching for a new leaf to eat: but most of the time it stays in one place, just swaying its long body to and



Photo, British Museum (Natural History)

Leaf-insect.

From Munro Fox's *Biology* (Cambridge University Press) fro a little, every now and then, to make itself look still more like a stick that is being shaken by the wind. The long, thin body is coloured greeny-brown, and the skin is rough like the bark of a twig, and the long, stiff legs look like sticks too. I don't know what sort of bird lives on stick-insects, but I'm sure that bird must find it difficult to collect enough of them for a good square meal.



Photo, D. A. Kempson

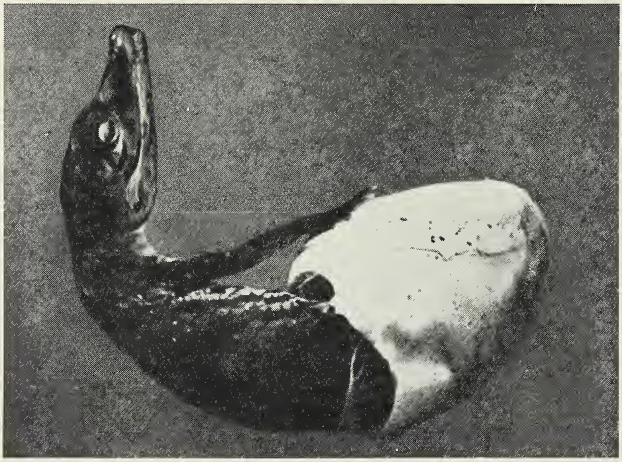
A stick-insect on a twig of privet.

CHAPTER XXXII

EGGS

ALL ANIMALS COME FROM EGGS – THE INSIDE OF A HEN'S EGG AND WHAT THE PARTS ARE FOR – THE LIFE-SPOT – FROG'S SPAWN – THE SIZE OF THE FOOD-STORES IN DIFFERENT KINDS OF EGGS – INSECTS' EGGS

WHEN you read the word 'egg,' I am sure you think at once of a bird's egg, because that is the egg one sees most often. We use birds' eggs for food, or we collect the beautiful, coloured shells just to look at for pleasure. But every living thing comes from an egg really. Here is a picture of a baby alligator coming out of its egg-shell, and on p. 229 you see a caterpillar hatching out from a hawk-moth's egg. Every kind of animal comes from an egg, though the eggs of most kinds are much smaller than the eggs of birds. And plants too have eggs. Away back in Chapter XVI, I explained that the seed of a plant may be compared with the egg of an animal.



Photo, W. S. Beveridge

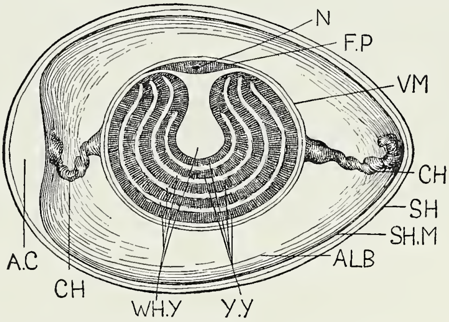
The hatching of an alligator.

But because everyone knows what a hen's egg looks like, I shall say something about that first.

When the hen's egg is laid, there seems to be nothing inside the shell but the 'white' and the yellow yolk-ball. The hen sits on her eggs after they are laid and keeps them warm with her body. And if the eggs are never allowed to get cold, and if they are 'fertile,' most extraordinary changes go on inside the shell; so that at the end of about three weeks, a cheeping sound is heard from within, the shell is chipped open at the broad end, and a young chicken comes out, complete with fluffy yellow feathers. When you look into the shell now, you find that it is empty: the white and the yolk have quite disappeared. It is an astonishing thing, when you come to think of it. Almost like a conjuror taking rabbits out of a hat. In the beginning, no bird: then at the end of three weeks, a perfect, young, live animal that can run about and feed itself.

Now it is not quite true to say that in the beginning there was *no* bird. If you look at the yolk of a fertile egg a day or so after it is laid, you will find a tiny reddish speck on one side of it. That reddish speck is the beginning of the chicken. I shall call it the 'life-spot' of the egg, because it really is alive from the very beginning. It is made of bird-protoplasm, and it has only got to grow and shape itself in order to become a chicken. The life-spot is the really important part of the egg, although at first it is so small in proportion.

In the picture there is shown a hen's egg cut open longways, so that you can see the parts inside the shell. The life-spot is the dark patch marked with the letters N and F.P. As the life-spot develops, we call it the *embryo*: when it has finished growing, it will have filled out the whole space inside the shell and it will have the shape and feathers and beak of a bird.



Hen's Egg cut longways. N and F.P, the future chicken; CH, egg-ropes; SH, shell; SH.M, shell-membrane; ALB, white of egg; Y.Y and WH.Y, yolk.

From Thomson's *Biology of Birds* (Sidgwick & Jackson, Ltd.)

If any living thing is to keep itself alive, it must have food and water: and if it is to grow, it must have a great deal of these. Supposing you were given a life-spot and an egg-shell and told to grow a chicken from that, surely the first thing you would do would be to stock the shell with a good supply of food? That, of course, is what the white and the yolk of an egg are – a supply of highly nutritious food along with enough fluid for the growing animal: and the life-spot, as you see, lies with its food all round it as it floats in the middle of the egg. There is just enough of this food-store to enable it to grow to the stage when it has the shape and all the parts of a young bird. The shell is merely a sort of box to hold the food-store and the growing bird, and to protect it from getting squashed. In a way, the shell is like the seed-coat of the bean-seed.

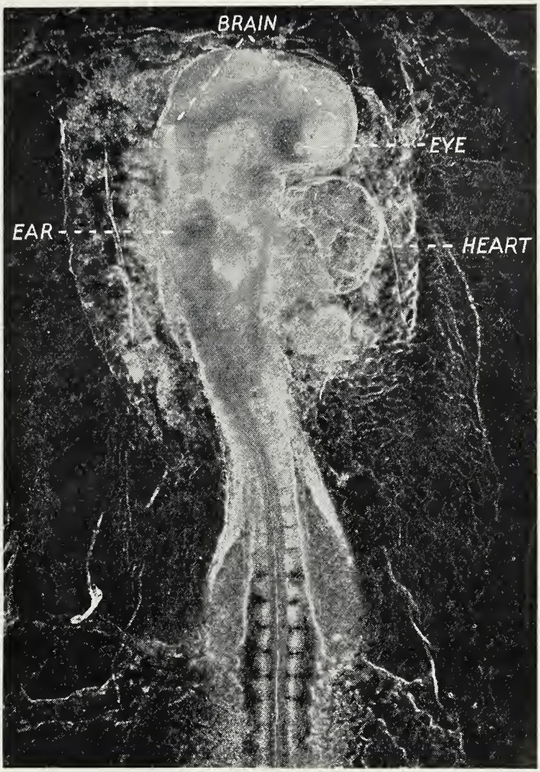
I said that the white and the yolk were a food-store. But let us be a little more exact. What are the food-stuffs that you would give an animal that was growing fast but taking no exercise? You would give it a good deal of the food-stuff that readily gives off heat, and you would give it still more of the food-stuff that is best for body-building. And water, of course. Well, what we call the 'white' of the egg is protein and water; and the yolk, the yellow part, is mainly fatty food-stuff, with protein and some salts and vitamins. All the things are there that the bird can want for food in its first three weeks inside the shell (which explains why a human being can make quite a good meal off a hen's egg).

You can compare the food-store here with the food-store in the seed of the bean. In the bean it is mainly a mixture of protein and starch, and in the bird's egg it is mainly a mixture of protein and fat. And these food-stuffs are in just the right proportions for the needs of the particular kind of living thing that eventually will come out of the egg or out of the seed.

The white of the egg doesn't really look white when the egg is raw. It goes white and solid when the egg is boiled. In the raw egg, the white is a sort of half-fluid stuff and transparent like glass. In the picture it is marked ALB, and you see that it fills all the outer part of the egg; while the yellow yolk-ball, with the life-spot on one side of it, floats in the middle. Notice these ropy things at the ends of the yolk: they are marked CH. They are made of a rather thicker sort of white than the rest; and each of them is fixed to the yolk-ball at one end and to the lining of the egg-shell at the other end. By means of these egg-ropes the yolk-ball is held in position in the middle of the white and is prevented from bumping against the shell: the delicate embryo will not stand any rough treatment. And if you roll an egg over and over, the yolk-ball will always swing round on its ropes in such a way that the embryo lies uppermost; and this keeps it as near as possible to the warm body of the mother bird, who is covering the egg with her feathers.

But something more than food, warmth and shelter is needed if life is to go on and if growth is to take place. There must be a good provision of air; or, to be more exact, oxygen. The air necessary for the chick's breathing gets into the egg from outside. The shell is not so solid as it appears. It is made of a hard mineral stuff – lime: the same sort of stuff that teeth are made of. But the hard, limy shell of the egg is pierced everywhere with tiny holes, through which the air gets in.

Just inside the porous shell, the egg is lined with a sort of wall-paper, two layers thick. If you peel the shell off very carefully, you can see this like a white skin, enclosing the fluid white. At the broad end of the egg, the two layers of this lining are separate from one another a little way, and in this space the air collects. The space is called the air-chamber, and it is marked AC in the picture. If you hard-boil an egg and peel it, you always find a little hollow in the broad end of the white: that hollow was made by the pressure of the air in the air-chamber.



Photo, D. A. Kempson

The embryo chick developing from the life-spot. As seen under the microscope about two days after the egg was laid.

All the time it is developing inside its shell, the chick is slowly taking oxygen into its blood and slowly setting free some carbon dioxide. But when it is almost ready to come out, it sticks its beak into the air chamber and draws a good sniff of air into its lungs: and this helps to give it strength to set about chipping its way through the shell in which it lies curled up. At the end of its beak it has a hard little knob called the egg-tooth: and with the egg-tooth it hammers at the shell, making one small hole after another until the end of the shell cracks off. Then the chick scrambles out, and stretches its legs and flaps its tiny wings for the first time, and dries its feathers in the sun, and looks about the great world of the farmyard. The egg-tooth falls off at once, for it is of no more use to the bird.

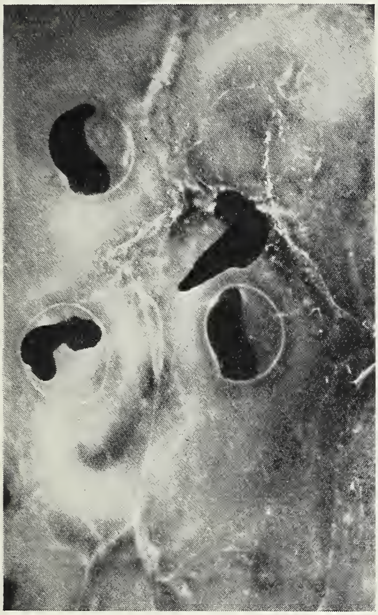
Frog and spawn.

This picture and two on p. 217 are reproduced by the courtesy of G.B. Instructional Ltd., from their film *The Frog* (produced under the supervision of Dr. Julian S. Huxley and Mr. H. R. Hewer)

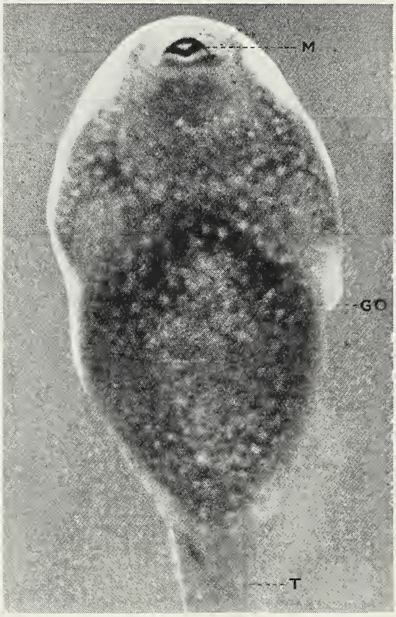
Every living thing begins as an egg. I said that in the first paragraph of this chapter; but I say it again now, because people so often forget it – one reason being that though some eggs are easy to see, others are so small that you may easily overlook them. Of course, you would expect a small kind of animal to have a small kind of egg. But that is not the only reason why some kinds of egg are so much smaller than others.

You can see, from what I have said about the bird's egg, that one reason why it has to be so large is because it has to hold enough food to carry the chick on until it is perfectly formed and ready to hatch out: a food-supply that will last a comparatively big creature three whole weeks takes up a good deal of room. But many creatures hatch out at an earlier stage: in such a case, there has not got to be so large a food-store, and so the egg is smaller in proportion. A frog's egg is a good example of what I mean.

The frog lays her eggs in a pond in the early spring. After they are laid, she goes away and pays no more attention to them. The frog is a cold-blooded animal, you may remember: and so it is not necessary for a frog's eggs to be kept at an even temperature in the way a bird's eggs must be kept if they are to develop. So the mother frog does not sit on her eggs. As they are laid, they are all stuck together in masses called 'spawn.'



A. Tadpoles hatching from the spawn. Some are still inside the eggs.



B. Young tadpole seen from the underside. M, mouth; GO, gill-opening; T, tail.

A frog's spawn looks like a heap of small crystal balls, each with a black dot in the middle of it. The black dot is the life-spot with its yolk-store. (You might look again at the picture marked 1 on p. 67.) The amount of yolk here is very small compared with what is in the bird's egg: small, I mean, *in proportion to the life-spot*. Outside the black dot is the clear, glassy covering: and this part corresponds to the white of the bird's egg. It is stiff and tough, however, because, since there is no shell, it has to act partly as a box. Its outside is rather sticky at first; and the eggs are all glued together by their sticky whites as they float in the pond. And as the mass of spawn floats, water seeps through the whites to the developing life-spot in each egg, and with the water comes oxygen for the breathing of the creature that is being formed inside. The white of a frog's egg seems to have a taste that other animals do not like: if a fish takes a mouthful of frog's spawn, it quickly spits it out. So this helps to protect the eggs from being used as food by other creatures.

In books of adventure one has read stories of ship-wrecked sailors getting a flame for cooking by means of a burning-glass. What they do is to take one of those glasses with curved surfaces that people use to magnify with, and they hold this over a bit of dry paper in the bright sunlight, at just such a distance that a very brilliant spot of light shines on the paper. After a time, the paper gets so hot where the glass directs that bright spot upon it, that it begins to scorch, and presently it bursts into a flame. Now it seems that the glassy envelope of the frog's egg may act in some such way. Of course I don't mean that the eggs get set on fire. But the heat of the sun is directed by the curved glassy surface of the envelope on to the embryo in the middle, just enough to warm it up: and this warmth helps the creature to get on with its growing.

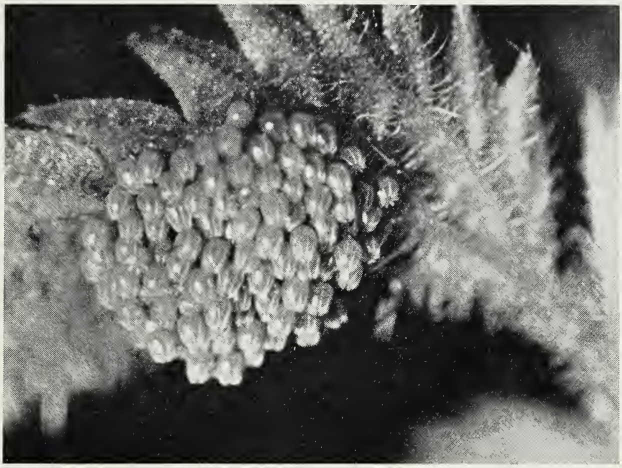
At the end of about a week after the eggs have been laid, you will find that the black dot has got longer: it is the shape now of a comma rather than of a full stop. And soon after that, the egg hatches. The creature that comes out of a frog's egg does not look like a frog. It has no legs, it swims by a long tail, and it breathes by gills like a fish. And as a tadpole it will swim about and feed and grow in the pond for another two or three months before it will turn into a tiny frog with legs and lungs.

You see the difference? A chicken goes through the whole of its development inside the egg, and when it comes out it is already a bird: a large food-store has to be provided for that, and so the egg is large in proportion. A frog, on the other hand, goes through only the first part of its development in the egg: and that is why the frog's egg need not have so much food in it, and so is very much smaller in proportion. The creature that comes out of the frog's egg does the rest of its developing outside, and gets food for itself while it is growing and changing.

Insects also work on this second plan. The creature that hatches out of an insect's egg is usually very unlike its parents. The young of flies and bees and butterflies come out of the egg as what we call a grub or 'larva' –

a little worm-like thing without any wings. And after it has left the egg, the grub has to feed and grow for quite a long time before it gets to the stage of turning into a winged insect like its parents. So there needn't be a very large food-store in an insect's egg. There must be just enough to enable the insect's life-spot to grow into a grub. Then it can come out and do the rest of its feeding and growing independently, in the way a tadpole does.

The eggs of insects are very, very small; but they are extraordinarily pretty and well worth looking at with a magnifying glass. You find batches of butterfly's eggs sticking on the underside of the leaves of many plants. Sometimes they are white, sometimes they are coloured, and often they are ridged and patterned very beautifully.



Eggs of a butterfly.

Reprinted by the courtesy of G.B. Instructional Ltd., from their film *Tortoise-shell Butterfly* (produced under the supervision of Dr. Julian S. Huxley and Dr. H. R. Hewer)

The mother insect always lays her eggs on the sort of stuff that the grub will like to eat when it hatches out. The common white butterflies that one sees so abundantly in the early summer lay their eggs on plants like cabbage for preference, because cabbage is the food their caterpillars will enjoy. The silkworm moth prefers to lay hers on mulberry leaves, because these are the most nourishing for silkworm caterpillars. The bluebottle fly chooses meat, because decaying flesh is what suits her maggots.

CHAPTER XXXIII

THE CHILDHOOD OF ANIMALS (i)

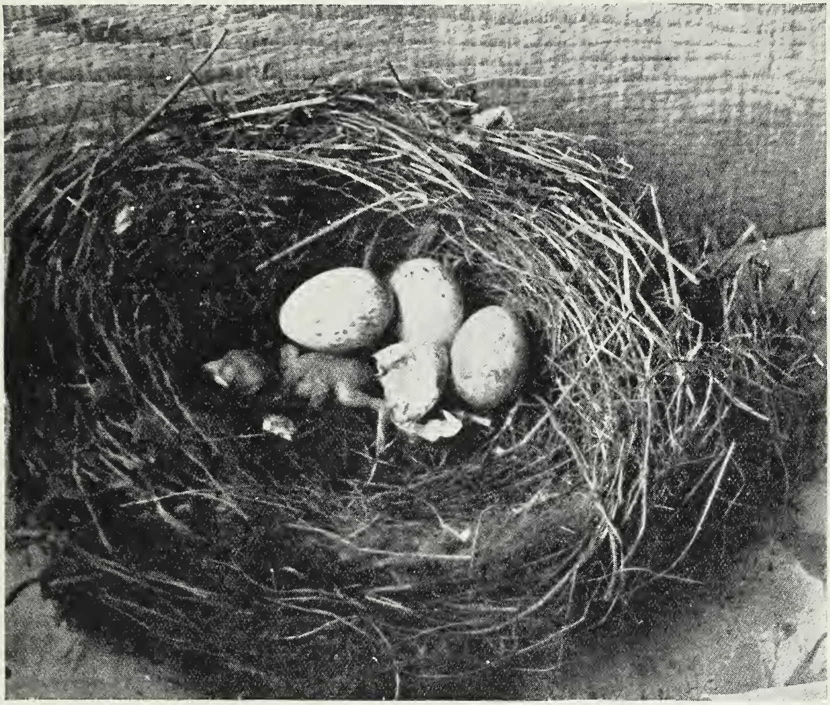
THE BIRD'S NURSERY – THE NUMBER OF EGGS IN RELATION TO POSITION AND SHAPE OF NEST – INCUBATION – DEPENDENT AND INDEPENDENT YOUNG – THE FOOD QUESTION – FRUIT-EATING BIRDS MAY HELP THE GARDENER – LEARNING TO FLY – CAT AND KITTENS – MICE, KITTENS AND LAMBS COMPARED – THE MOTHER'S MILK – THE VALUE OF PLAY

WHEN I was describing the bird's egg, I took the hen's egg as an example. But the description will do for any sort of bird's egg, really; inside they all look much the same. Eggs differ from one another in size, of course: generally speaking, small birds lay small eggs and big birds big eggs. And the shell is often more brightly coloured than the hen's egg, which is just a plain creamy tint or the colour of very milky coffee. Some birds lay light-blue eggs, and in a great many the plain background is marked with spots and streaks of darker shades. The shape varies, too; some eggs are narrower and more pointed than others. But inside they all have the same parts that I described in the hen's egg, and, in all, the young bird develops in the same way from the life-spot.

Before the eggs are laid, a nursery is prepared by the parent birds. In the spring, the father and the mother bird get very busy. They choose a good place: and the place that seems good to them depends on the kind of bird and how it likes to live. Thrushes and finches go for trees, bushes and hedges: woodpeckers and tits choose holes in trees and walls: sand-martins nest in burrows in sand-pits: starlings and swallows make for houses and out-buildings: and a whole lot of birds prefer the open ground – skylarks, for instance, and partridges and curlews make their nests on the ground.

The shape of the nest depends a great deal on the position that has been chosen; and it also depends on how long the bird-family will occupy it. Nests in the open are shallow and wide: some ground-nesting birds do no more than scratch a little hollow and line it with bits of dried grass. But most small birds make cup-shaped nests; and these are often elaborately constructed of twigs and moss, which the bird weaves together with its beak and feet. The mother does most of the weaving; but the father takes a share, and he does a lot of the collecting of suitable building materials.

As the walls grow, the bird gets into the nest and turns round and round to give it a good shape. The tits' nests are among the loveliest: the walls are a sort of feltwork of lichen and moss and wool and spiders' webs. And then the whole, when it is finished, is carefully lined with soft stuff, usually tiny feathers. The nest of even a small tit may contain as many as 2,500 feathers. This lining keeps the heat in, and it makes a soft resting-place for the brittle eggs and for the young birds when they hatch out. You can see that a tremendous amount of labour must go to nest-making. Some people help the birds in spring by hanging up bunches of small feathers and wool and horse-hair by the bird-table where they put the



Photo, M. H. Crawford

House-sparrow's nest and eggs, with one newly-hatched bird.

food, so that the animals have not to go so far in search of the right materials.

When the nursery is ready, the mother bird lays her eggs in it. The number of eggs is related to the shape of the nest. The partridge, in her open, shallow ground-nest, sometimes lays as many as twenty eggs together. But about five eggs is perhaps the average in the deeper, cup-shaped nests. There must not be too many for the parent bird to cover easily as she sits on the nest, for they must be kept at the even temperature of her own body. If she is frightened away by some unkind person, the eggs get cold and the young things inside them die.

But the parent bird is very brave and she sits close until the last moment, trusting for protection to her stillness and to the nest's looking so like the twigs and bark around it. Even the sharp eyes of the hawk may be deceived if she keeps still. Some birds seem to lose their scent while they are brooding on their eggs. A dog can usually smell out a partridge easily enough; but I have been told that, when she is sitting on her eggs, he may come within a foot of her without noticing anything.

The mother bird does most of the sitting, though the father sometimes takes his turn. The father's main duty, however, is to bring his wife plenty of food, and to cheer her up by singing to her when she gets tired. For it is a long, weary job. The robin redbreast sits for thirteen days: the swallow for fifteen days: the hen's egg takes twenty-one days to get to the stage of hatching: the swan's egg must be covered for nearly six weeks.

At the end of this time, whatever it is, cheeping sounds are heard from inside the eggs; and one by one the baby birds chip through their shells and come out into the nest. It is interesting to notice that, with different kinds of birds, the young hatch out at different stages. The chicken that comes out of the hen's egg is covered with soft, fluffy, yellow feathers: it has strong legs and can run about at once, and it has a good strong beak with which it soon begins to pick up seeds for itself. Ducklings come out like that, too: so do snipe and peewits and partridges. From the first, the young of these birds are wonderfully independent.

But with many other birds – sparrows, thrushes, blackbirds and the like – the young are hatched out practically naked and very feeble, and their eyes are closed at first. If the parents were not there to look after it very closely all the time, a nestling of this kind would soon die of cold and hunger. The parents of such young continue to sit on the nest for a long time after the eggs have hatched, keeping their family warm and cosy, or, if the weather is very hot, protecting them from the fierce rays of the sun. And they bring food and push it into the wide-open mouths of their children, who have no sooner swallowed a meal than they open their yellow-edged beaks again and hungrily squawk for more.

The food the parents provide for their young is often quite different from what they would choose for themselves. The parent birds have strong beaks and strong stomachs, and probably they feed a good deal on seeds and hard things like that. But the babies couldn't digest seeds: they must have something very nourishing which is also soft and easily digested. So what the parents usually give them are caterpillars and bits of earthworm. The parent crams this stuff into the nestlings' open mouths and right down their throats until sometimes you'd think they must choke. Some birds – chaffinches, for instance – partly digest the food themselves, and then bring it up into their mouths and feed it to their young. And

Photo, J. Markham

Marsh-warbler feeding its young.

pigeons give their squabs a very nourishing, milky-looking stuff that they make themselves from the lining of their crops. (The bird's crop is a sort of pouch in the front of its gullet. *See* picture on p. 127.)

It takes a lot of doing to keep a family of young birds satisfied. A man watched a hen chaffinch, and he saw her feed her babies twenty-four times in a hundred and thirteen minutes: that's to say, they were getting something to eat about once every five minutes! I have seen it stated that a single pair of great tits collect something like eight thousand caterpillars for their nestlings during the twenty days that must pass before the children can begin to get food for themselves. That means very hard work, when you think of all the flying about, as well as all the searching and the carrying. Indeed, when a bird has young to look after, it works for seventeen hours out of the twenty-four. No wonder that the young grow fast on all this nutritious protein food; their eyes open, their limbs strengthen, their skin gets covered with the sprouting feathers.

People who love their gardens often get furious with the thrushes and blackbirds that eat the raspberries and the other fruits in summer. And sometimes these people go and destroy the birds' nests in the spring. But supposing there were no birds to eat up the caterpillars? I assure you, if there were no birds about, the gardens would be much more spoiled by caterpillars than ever they are by birds. In one State in America they calculated that the birds destroyed 176 cartloads of harmful insects every year. So the farmer and the gardener probably owe a good deal more to the birds in spring than they lose by them in summer. It is worth bearing this kind of thing in mind. People who go and destroy large numbers of one kind of animal may be letting themselves in for far more trouble from other kinds which were kept in control by it.

The parent-birds' duties do not end with this ceaseless feeding of the young. They also have to keep the place clean. The young birds, crowded together in the nest, would soon make the place very dirty, and that would be most unhealthy. So the father and the mother clear up all the mess their children make and push it out every day, so long as the little ones are too feeble to leave home.

But by degrees, as their feathers grow and their bodies develop and their legs and wings get stronger, the young grow restless in their crowded nursery, and they begin to want exercise. They get out and stand by themselves on the branches for the first time, rather shaky and frightened. And now the parents have to urge them to use their wings. This is a very alarming adventure for them, and they squeak and squawk. But their parents assure them it will be all right if they will just trust themselves to the air and their own strength. You know how it is when you are learning to swim. If you are not afraid of the water, but trust yourself to it and don't let your muscles get paralysed with fear, you will learn the stroke much more quickly and soon be paddling along quite well. Often the parent birds give prizes to the young ones that do well. Last summer I was watching a thrush teaching her young to fly. I noticed that she had her beak full of caterpillars: and every time one of the bird-children summoned up its courage and fluttered to the ground, she came up to it and gave it a caterpillar as a reward.

While the young brood are trying out their wings and learning to fly, they are in considerable danger. You see them on the ground, hopping about under cover of the bushes and within easy reach of cats. The parents show great courage while they have young ones or eggs to protect. They will even attack an animal much larger and stronger than themselves and drive it off. By the time their children are fully fledged and able to fend for themselves, you would think the parents had had enough of hard work for one season. But some kinds proceed to raise a second brood later in the year, and go through the whole business again.

Perhaps I have given too much of this chapter to the childhood of birds. But it is good to get into the way of watching them. Even in towns you can see a lot of bird-life, if you know how to watch pigeons and starlings and sparrows. To watch other kinds of young animals in a wild state is very much more difficult, even in the country.

But almost everyone has either a dog or a cat at home. If your cat has had kittens and you have seen them soon after they were born, you will have noticed that their eyes are still not open and that they are very weak and helpless. For a time they are quite dependent on the mother cat. They snuggle up to her for warmth, she feeds them with milk from her body, and she licks them all over with her prickly tongue to keep them clean. As they get a bit older, their eyes open and they begin staggering about on their wobbly legs. Little by little, they get more independent, and by the time they have learnt to lap milk from a saucer and to clean themselves, it will not do them any harm to be on their own. They don't know how to lap milk in the beginning: it is a thing they have to learn. I daresay they learn partly by imitating their mother when she feeds; but I think she tells them a good deal in cat-language. Have you ever noticed that cats which were taken too young from their mothers scarcely ever purr? It may be that when they left home they were still too young to be educated in that part of cat manners.

Puppies are like kittens in being helpless at first, and blind. But at least puppies and kittens have a nice thick coat of fur when they are born. Young mice, however, are naked as well as blind – little red, skinny creatures, even more naked than the young of a sparrow or a thrush.

On the other hand, there are young mammals that are active and partly independent almost from the first, after the manner of chickens or ducklings among the birds. Lambs can frisk about soon after they are born, and they can see from the beginning. It is the same with calves and with foals; they run alongside their mothers within a few hours of coming into the world.

Can one explain this difference in the appearance and behaviour of kittens, puppies and mice, on the one hand, and of lambs, calves and foals on the other? I think one can say that it is connected with the life the parent animals would lead in a wild state. Mice live in holes and rear their young in nests there, secretly hidden in the dark. And, in their wild state, cats and dogs (like lions and wolves) rear their young in sheltered dens. So there is no necessity for the young to be strong on their legs at first: they develop quietly in shelter, and the parents bring food to them as they require it.

But it is very different with sheep and cattle and horses. You have to remember that these farm animals of ours were not always the mild, looked-after creatures they are now. Their ancestors were wild animals, which, long ages ago, men caught and tamed. And in some parts of the world there are still wild breeds. Now the natural habit of life for sheep and cattle and horses is to go out in herds to graze on the plains or mountain slopes, where there is little cover. In such conditions they are in danger from the attacks of fiercer, flesh-eating animals, such as wolves. So clearly it is a great advantage for their young to be able to run with the rest of the herd if the enemy comes near. And our farm animals, although in no such danger any more, still keep up the habit and have very independent young.

But even the frisky lambs and the nimble calves and foals are all dependent at first on their mother for *food*. All mammals, whether they be kittens or lambs or human babies, are fed at first on their mother's milk. Milk is a most perfect food. It has all the necessary food-stuffs in it, in just the right proportions. Each of the mammals has its own kind of milk: a horse's milk or a goat's milk, for instance, is not exactly like cow's milk. But each has the special proportions of the essential food-stuffs that will suit the particular kind of young, whether it be foal, or kid or lamb; and on milk the mammal lives until its stomach is strong enough to digest the tougher food of the grown-up animal.

When we watch kittens running after their own tails, or when we see lambs leaping suddenly into the air and flapping their woolly tails, we say that they are 'playing.' All young mammals play, if they are healthy. If a child never wants to play, you may be sure that there is something the matter with it. No doubt the animals play, just as we do, because they enjoy it. But in addition to giving the animal pleasure, play does its body great good. Play strengthens the muscles and expands the lungs and makes the blood flow freely along the blood-vessels and makes the digestion work well. Moreover, through play, the young animal begins to practise how to spring effectively and how to judge distances with its eyes. A kitten that tears round and round the room chasing its brothers and sisters, or rushing up the curtains, or leaping from chair to chair, is not merely letting off steam and having a good time: it is preparing its body for what it will have to do when it grows up, and when there will be no mother cat to depend on for food and for protection.

CHAPTER XXXIV

THE CHILDHOOD OF ANIMALS (ii)

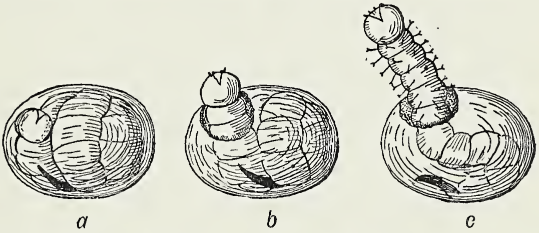
ANIMALS THAT 'METAMORPHOSE' – THE SILKWORM IS AN INSECT – HINTS ON REARING SILKWORMS – THE LARVA – GROWTH – THE COCOON – WHAT SILK REALLY IS – THE PUPA – THE GREAT CHANGE – THE DRAGONFLY – THE ANT'S NURSERY – AN 'ANT'S EGG' IS A COCOON – TADPOLE INTO FROG

THE young animals we have been considering are like their parents really, only much smaller. It is true that they are sometimes born naked and blind: but gradually, as they get bigger, they grow their feathers or their hair, and their eyes open; gradually the baby bird or the kitten becomes a creature like its father and mother. There is no sudden change.

But, as I suggested in the chapter on eggs, with some animals it is different. Some animals, when they are born, are so utterly *un*like their parents that you would never guess they were members of the same family. Creatures like insects and frogs are the kinds I am thinking of, and here I am going to say something about the childhood of these animals.

As an example of an insect, I shall choose the silkworm moth, because it is easy to keep and rear in captivity, and you can watch the whole thing for yourself if you follow my directions. You can buy the eggs of the silkworm moth from a dealer for about a shilling a hundred. I advise you to buy them in the spring, because, in the natural state, the eggs hatch in April. Put a paper tray at the bottom of a card-board box (not a *tin* box, please), but put *dry* lettuce leaves on the tray. Then place the eggs on the lettuce. Silkworms like mulberry leaves best, but these are difficult to get; and if you can't get lettuce, then dandelion leaves will do. You should cut a bit out of the lid of the box so that light and air can get in and stick muslin over the hole. If the air is warm enough, the eggs will hatch in a few days, and out of each will come a little worm-like animal with black hairs on it. (The first picture in this chapter shows the egg of another kind of moth hatching; the animal has bitten a hole in the egg-shell and through that hole it escapes.) The little creature is quite active and able to look after itself from the first minute, and it immediately begins to eat the leaves you have provided for it. It chews at the leaf with its tiny jaws, and feeds at such a rate that it grows very fast. You must put in new leaves from time to time, and you must very often lift out the tray and clean the place thoroughly if the animals are to thrive. In the picture on p. 231, the silkworm is shown at different stages of its growing. You see how tiny it is in the little picture marked 2; but by the time it is full-grown it is nearly three inches long. An immense amount of mulberry leaf or lettuce is needed to make it grow as much as that; but if there is plenty of food and if the air is warm, all the growing can be done in three weeks. By the time the animal is the size it has reached in picture 8, it has lost its black hairs and its colour is a sort of greenish-yellow.

All this time the young silkworm is what we call a grub or a larva. The larva of a butterfly or of a moth is called, as you know, a caterpillar. Now I want you to look at that picture 8 more carefully. You see the animal's little, roundish head, where the eyes are, and the jaws? Then comes a humpy, wrinkled part with three pairs of short legs like claws. Insects never have more than three pairs of jointed legs, even when they are grown up. Then comes a fat, jointed part; and on some of the rings are pairs of little stumps for clinging to the leaf with. They are called the false legs, because you do not find them in the grown-up insect. And then notice these dots along the side of the caterpillar, like a row of port-holes on the side of a steamer. These are the breathing-holes.



Egg of eyed hawk-moth hatching. *a*, egg containing young larva; *b*, shell breaking; *c*, young larva coming out.

From Eltringham's *Butterfly Lore* (Clarendon Press, Oxford)

Now here is a thing that lots of people do not know. An insect like this does all its growing while it is a grub. After it is a grown-up insect with wings, it never grows any bigger. Sometimes you will see a house-fly that is smaller than the other house-flies; but this doesn't mean it is a young house-fly that hasn't finished growing. It means that when that fly was a grub it didn't get enough to eat, or else it wasn't warm enough; so it didn't grow well. Its growth was stunted when it was a child and so it always has to remain a dwarf.

As the caterpillar grows, it gets too big for its skin and the skin becomes too tight. So every now and then the caterpillar's skin splits right down the back, and the creature comes out of its old skin, with a new, larger skin already on its body. This is called 'moulting.' The silkworm caterpillar moults four times before it is as large as it is in picture 8. Then it begins to get ready for a long rest it is going to take while it turns into a moth.

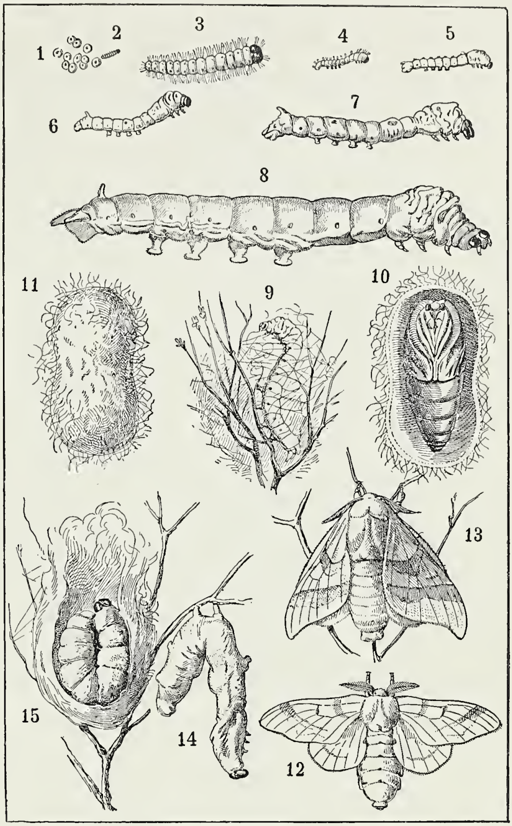
It makes a sort of house for itself first. We call this rest-house its cocoon. The cocoon is shown in picture 11; and just below that, in picture 15, the caterpillar is seen curled up inside: one of the walls has been cut away to show it. The cocoon is of a golden-yellow colour and it is made of silk. All the real silk cloth in the world is made from the threads that formed the cocoons of silkworms.

The caterpillar spins this silk out of its mouth. It makes a sort of sticky fluid inside its body and dribbles this out through a hole at the end of its tongue. And, as the fluid comes out into the air, it gets firm and tough. Gradually, as more and more fluid pours out and 'sets,' a long, golden thread is formed. Most kinds of caterpillar can make some silk; perhaps you know the little tents of grey silk that some caterpillars shelter under when they are out feeding on the leaves? And then think what a useful thing it is for a caterpillar that falls from a branch to be able to spin a silk rope as it falls so that it is let down gently to another twig; or it can climb back along its rope if it wants to. But no other caterpillar can make so much silk, or such tough silk, as the silkworm makes. In the picture marked 9 you see the silkworm beginning to spin. You see how, first of all, it spins a sort of loose cage of silk threads attached to the twigs or bits of leaf round it: some of the silk strands are arranged lengthwise, and others criss-cross between these. Then it sticks more and more silk threads on to this scaffolding, until the whole is pretty firm. Now it sets to work on the really serious spinning inside this outer fence. For three or four days, without ever stopping, it spins and spins and spins a long, long golden thread from its mouth, turning its head to and fro as it winds this thread round and round the inside of the cocoon, making the wall thicker and thicker. If you were to unwind on to a bit of card the silk thread of this inner part, you would find that, with a big cocoon, it might be as much as 1,000 yards long.

It is a good plan to make little cones of paper and put them in the box with the silkworms when they are about full-grown. Then they will spin their cocoons inside the paper cones and you can lift these out and, until the walls get too thick, you can watch what is going on.

All through this spinning business, the caterpillar gets nothing to eat, and in making the silk it uses up a great deal of energy and of the food-stores inside itself. So by the time the cocoon is finished, the creature has actually shrunken a good deal, and its skin, too big for it now, has fallen into wrinkles. Now it goes into a resting stage inside its golden house. But it only *seems* to rest. Really, it is passing through an extraordinary change. You see that in picture 10. This stage is called the chrysalis or pupa. 'Pupa' is a Latin word meaning a doll: and there is something so stiff and toy-like about a pupa that it is difficult to believe it is still alive inside its hardened skin.

It takes about a fortnight for the changes to happen in the pupa that turn the young animal into a grown-up moth. At the end of that time, it seems to wake up, comes out of its skin and out of its cocoon, and escapes into the air with two pairs of wings on its body and with antennæ and great glistening eyes on its head. Picture 13 shows the female moth: the male is shown in picture 12, with his wings spread out. He is a little smaller than the female, and his antennæ are more feathery



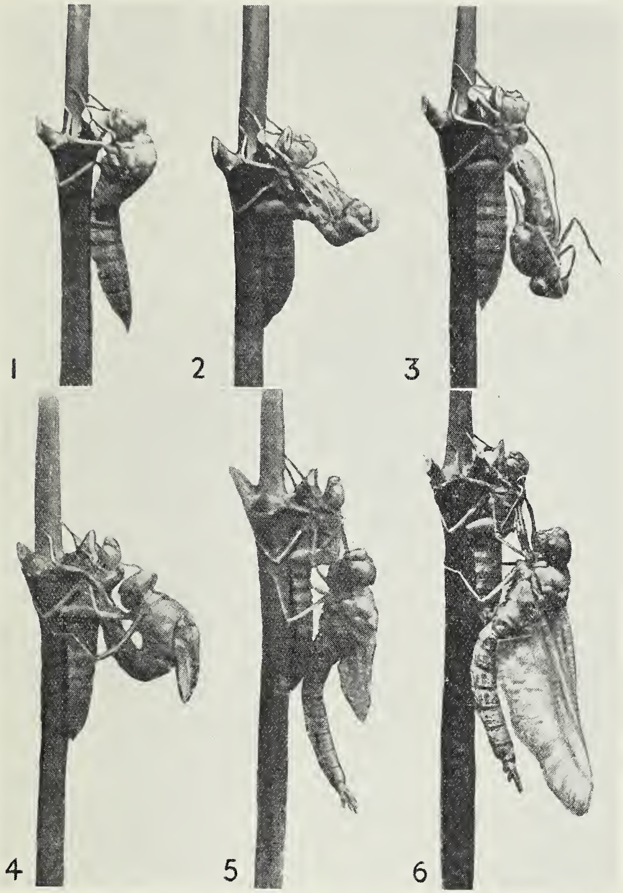
Life-history of the silkworm moth. 1, eggs; 2, newly hatched grub (larva); 4, 5, 6, 7, the larva after successive moults; 8, the full-grown larva; 9, the silkworm larva beginning to spin its cocoon; 10, cocoon cut open to show the pupa inside; 11, a cocoon from the outside; 12, male moth with wings spread; 13, female moth with wings folded; 14, a larva that has died before spinning its cocoon; 15, a larva that has died before it has finished its cocoon.

From L. Joubin and A. Robin's *Les Animaux* (Larousse, éditeur) than hers. The females will soon lay eggs, and you can start a new brood. It is a good plan to twist small screws of paper and put these in the box for the moths to lay their eggs on. If you want to collect the silk, you needn't let all the moths come out. If you drop some of the cocoons into boiling water, that will kill the pupæ inside: then tear away the outside floss, and wind off the golden silk on a strip of card of which you know the width, so that you can measure the length of thread your caterpillar has spun.

What I have been telling you about the silkworm is true of other moths too, and true of butterflies. I mean that what comes out of the egg is a caterpillar: and after growing to full size, the caterpillar rests as a pupa, and then the great change takes place that turns it into the winged insect. Sometimes the pupa stage lasts a long time; in some butterflies it lasts all through the winter. Every kind of caterpillar has its own particular kind of food, and, as I explained in Chapter XXXII, the mother insect is careful to lay her eggs on suitable food-material.

Some insects, though they live in air when they are grown up, lay their eggs in water: and the young, when they hatch out, live under water and do all their feeding and growing down there in the pond. The dragonfly is a good example of that. The grown-up insect is a gorgeous creature. Its body is bright blue or green or red; its wings have rainbow lights on them as it flies; its great eyes flash in the sun like jewels. It lays its eggs in ponds or streams; and the young creature that comes out of the egg is a rather dingy-looking, brownish-greenish thing, very unlike its handsome parent. The young of the dragonfly *is* like its parents, however (and unlike the caterpillars I have been describing), in that it lives on flesh.

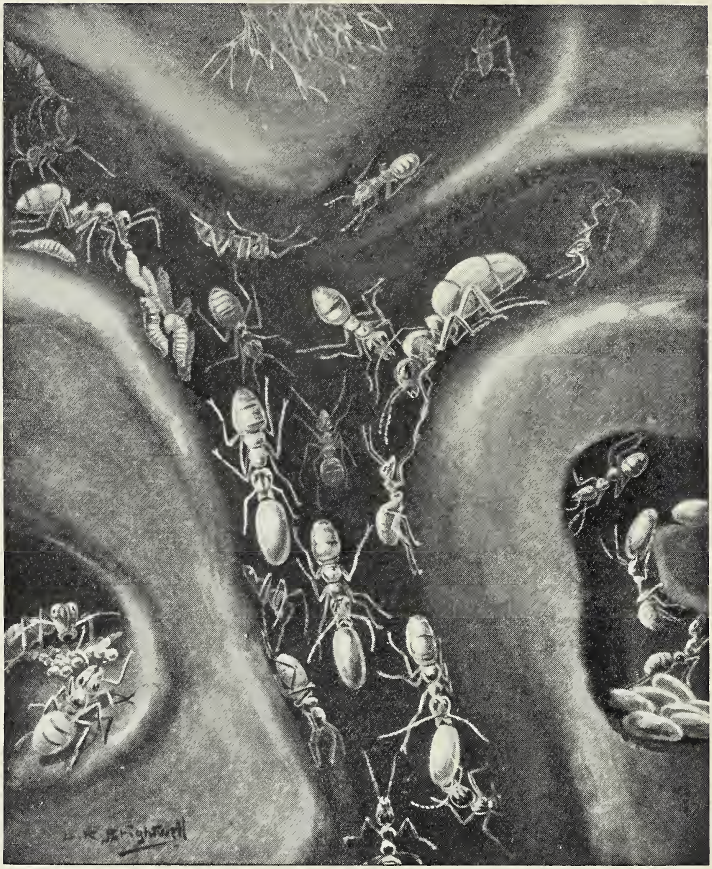
The larva of the dragonfly lives in this dim, under-water state for a long time – as much as two years, even. Then at last it is full-grown and ready for its great change. Slowly it climbs up a water-weed and comes out of the water into the air for the first time. Changes have been going on under its skin since its last moult; its wings have been forming, and its great eyes, and its antennæ. And now, after it comes out into the air, the skin splits along the back in the front part of its body, and the perfect insect begins to squeeze its way out of its old covering. The photographs on the opposite page show that happening. In 2 it has got its shoulders out: in 3 it is nearly all out, but the tail has stuck. So, in 4 it has bent forward and, by a mighty effort, it is pulling its tail out of the old, dead skin. In 5 it is all out, and is resting for a while on the empty skin, while its body dries and its wings expand. When the wings are fully expanded and dry, the dragonfly will whizz away in the sunshine to catch flies until the time comes for it to lay eggs and start a new brood.



Photo, Ray Palmer

Dragonfly. The change from water-life to life in air.

These insects – moths and butterflies and dragonflies – take no notice of their eggs once they are laid, and they pay no attention to their children when these hatch out. But some insects take almost as much trouble over their young as a bird does. Ants are like that, and bees. These are



From colour plate by L. R. Brightwell

The ant's nursery. Part of a nest of the yellow meadow ant of Great Britain, laid open to show what is going on inside. The soil is riddled by burrows running in various directions. Above, on the left, an ant is feeding some larvæ. On the right is a queen with workers in attendance. Below, on the left, some eggs may be seen; in the centre and on the right, the ants are carrying pupæ from place to place.

From Wells, Huxley and Wells' *Science of Life* (Waverley Book Co. Edition)

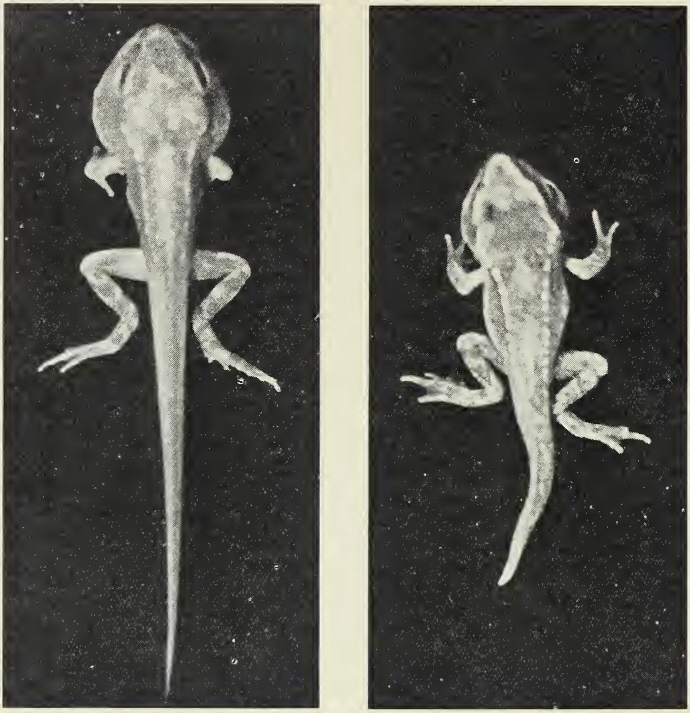
insects that live all together in a great house that they arrange for themselves: and in special parts of the house are nurseries for the young. The picture above shows part of the inside of an ant's house. The ants have built all these walls and tunnels and little rooms in the earth. On the left, at the bottom, you see two ants arranging the eggs. In the tunnel near the top on the left, an ant is feeding some of the grubs that have hatched out: you see she is pushing food into their mouths, just as a bird feeds its young. Then in the middle, in the tunnel, you see ants running about with the pupæ in their mouths. The pupæ are inside these big, white things that look like eggs. They are not the eggs, though; the eggs are much smaller and more round in shape. When you buy what are called ants' eggs at the dealer's, to feed your gold-fish with, what you are buying are really ants' pupæ in cocoons.

On the right of the picture, below, you see the ants arranging the cocoons in another little nursery, where they will rest until the time comes for the great change. Out of these white cases will come full-grown ants presently. That larger, paler ant near the top of the picture on the right is called the queen, and it is she who lays all the eggs. She is the mother of all the other ants. The other ants that you see in the picture are just nurses and housemaids.

We have seen that the animal that comes out of the frog's egg is not a bit like a frog. We call this larva a tadpole, and it feeds on the water-weeds in the pond or in your aquarium, and grows very fast at first. It has a long, finny tail, and swims by waggling it to and fro, the way a fish does. And it breathes by gills, like a fish, getting oxygen into its blood from the air dissolved in the water. But it hasn't got paired fins like a fish, you'll notice; nor has it any scales.

The parent frogs have large bulging eyes and very wide mouths and no tail. The tadpole has small beady eyes, and its mouth is quite small. The parents have two pairs of legs; long, hind-legs for jumping and swimming with, and short, bent front legs; the young tadpole is quite legless. Another difference is that the grown-up frog has lungs for breathing with and draws air through its nostrils. (Look back at the pictures on pages 67 and 217.)

The change begins when your tadpole is about eight or nine weeks old. Its legs begin to sprout. At first they are tiny little things, one each side of the root of the tail. The front pair are growing too, but for a time they are hidden away under the flap that covers the gills. And as the legs grow longer, the gills begin to wither away and lungs develop instead. The animal comes to the surface for air. About this time too it develops a taste for meat: pond-weeds do not satisfy it any longer. So you must



A Tadpole into Frog. B

A, Tail still fairly long; B, later stage, with tail much shorter.

Reproduced by the courtesy of G.B. Instructional Ltd., from their film *The Frog* (produced under the supervision of Dr. Julian S. Huxley and Mr. H. R. Hewer)

give your tadpoles scraps of raw meat when their legs are growing; otherwise they may eat one another for lack of the right food. While it was a vegetarian, the tadpole had a very long intestine; but with the altered diet the alimentary canal shortens.

Now at last the great change takes place which finally makes the tadpole into a frog. Its tail gets shorter and shorter: its legs get longer and stronger: its eyes increase in size and bulge out on the top of its head, and its gets a frog expression on its face: its mouth grows wide and has little teeth in the upper jaw. When the tail has quite gone, the animal is somewhere about three months old and is ready to come out on land and hop about. Except for its small size, it is now just like a grown-up frog.

CHAPTER XXXV

HOW ANIMALS LIVE TOGETHER (i)

SOCIABILITY – THE FAMILY AND THE TRIBE – BUTTERFLIES AND FROGS HAVE NO FAMILY LIFE – IT IS VERY DIFFERENT WITH BIRDS AND WITH MAMMALS – BUT THEIR FAMILY LIFE SOON ENDS – THE ROOKERY – THE WOLF-PACK – THE HERD – DIFFERENT DUTIES FOR THE MEMBERS

BEFORE we go on to the animals, I want you to think first about the ways we human beings live together: and after that, we can make some comparisons.

While it is true that some people like to be by themselves most of the time and feel miserable in a crowd, the majority are unhappy if they are much alone, and they feel more at ease in a large company. On the whole, it is true that we human beings are what is called 'sociable.' We need to be with others of our own kind, part of the time anyhow – even those of us who really enjoy solitude.

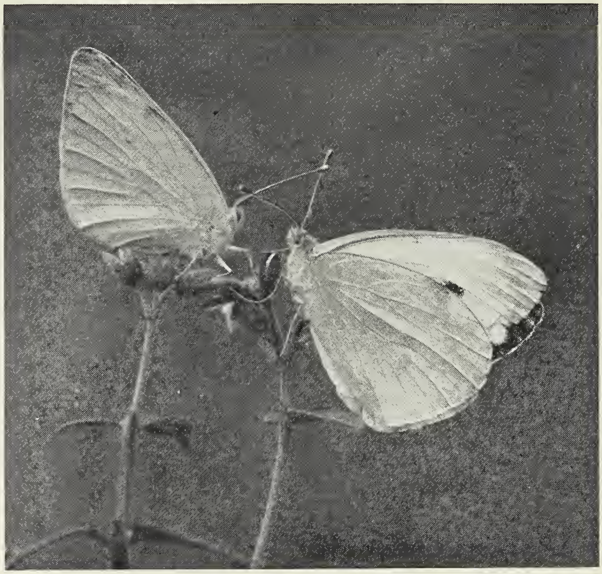
Next I want you to think of the ways in which human beings band themselves together to make what is known as 'society.' The smallest group is the family – the father and mother and their children. Although it is such a small group, the family is a very important group for us, and it holds together long after the children are grown-up, and perhaps even after they have children of their own.

Now suppose you were a wild savage living in a jungly forest in some tropical country like Africa, where there were fierce animals. And suppose you married another savage and had little black children. You might find it a great convenience to join up with some other friendly savages in the neighbourhood and all keep your families together. You would probably get along much better that way. It would be safer, for one thing. All the grown-up men could band together for hunting, and for driving off lions and leopards; and they could also defend themselves and their wives and children much better from the attacks of other savage warriors. Families bound together in this way make what we call a *tribe*; and generally all the families in a tribe are related to one another by marriage.

Of course there are many other ways for people to band themselves together. But, at the moment, I am concerned only with these two – the family and the tribe.

You will find that many animals are quite as sociable as we are; but some animals prefer a solitary life.

Think of a butterfly, for instance. The butterfly lays its eggs on a green leaf and goes away. Out of the eggs come presently the caterpillar children.



Photo, John J. Ward

Two butterflies in conversation.

But they never see their father and mother. The father and mother butterfly, if they met their young family later, wouldn't even recognise them. The young have to look after themselves; and, beyond choosing the right kind of leaf for them when she lays her eggs, the mother does absolutely nothing for them at all. There is no family life. Grown-up butterflies may meet one another on the flowers and carry on some sort of conversation with one another, perhaps; but they don't share any home and they are all very independent.

It's much the same with frogs. After the mother has laid her eggs in the pond, she leaves them to chance: no one looks after the tadpoles that hatch out. Some are eaten by fishes and some are eaten by ducks. The remaining ones have to look after themselves and get their own food. There is no home life, no family life, among frogs.

It is a very different thing, however, when you come to the birds. Some birds stick to the same wife, year after year. And, instead of laying hundreds or thousands of eggs, as a butterfly does or a frog, the mother bird lays only a few. For she is not going to leave her young to chance. She and her husband prepare a nursery for them before they come, and after they are hatched there is a very real family life until the children are fully fledged and able to manage for themselves. But now, here is where a bird's family life is different from ours. Once the children are able to fly and feed, the parents lose all interest in them. They may proceed to raise a second family that same summer: and if they met their first children now, they probably wouldn't know who they were. You would think it pretty queer, wouldn't you, if your father and mother forgot about you the moment your education had ended and you were able to earn your own living!

But it *is* that way with birds, and with most of the furry animals too. If your cat has kittens, she is very good to them while they are blind and helpless: she feeds them and warms them and cleans them and fusses over them, and certainly she loves them. But after she has taught them how to lap milk and how to wash themselves and how to purr, she begins to get bored with them, and perhaps then you give the kittens away to your neighbours. The mother cat scarcely misses them after the first day: and, if you were to bring back one of these kittens some time later, when it had grown a bit, she wouldn't know it; she would probably spit at it with rage, thinking it was a stranger.

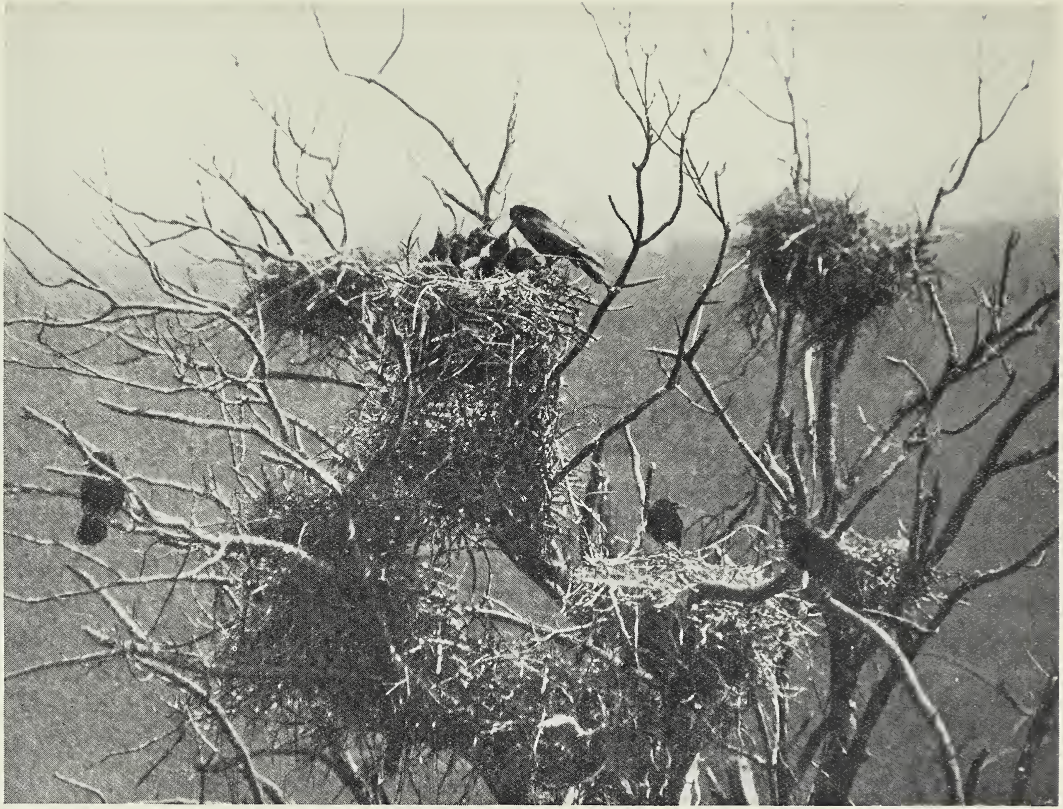
With these warm-blooded animals, then, there is a real family life; but as a rule it lasts through only one season, and usually it ends when the children are able to look after themselves. And in all the kinds I have mentioned, each little family lives separately. Whether one thinks of a blackbird or of a wild cat, it would be true to say that each family lives quite on its own, and each is made up of just one full-grown male, one full-grown female, and the few children that they rear. But some kinds of birds have several wives at a time. The cock in the farmyard, for instance: he has ever so many hens for his wives, and each of these may have chickens. So his responsibilities are increased. No doubt that is one reason why the cock is so big and strong and why he is so much fiercer than the hens. For if they were all in a wild state, living in the jungle, the cock would have to do a lot of fighting to secure enough food for his large family of hens and chickens, and he would have to drive off enemy animals that might eat the more defenceless birds if they got a chance.

With other sorts of birds, again, you will notice that, while each has its own nest and each husband just one wife, the nests are all built close to one another, and the birds fly about together in flocks. The rook is a very good example of a bird that has this sociable arrangement. In the early spring, the rooks build their large, rather untidy nests of sticks, high up in the bare branches of the taller trees: there may be twenty or more nests quite near one another, and each belongs to one family. It is a sort of bird village, and all very sociable, with a tremendous cawing and noise going on in it while daylight lasts. And if you get up early enough in the morning, you see great companies of rooks flying off from the trees into the fields all together to hunt for food: as evening falls, you see them flapping back together to their villages, still in great companies.

The starling is another very sociable bird, whose habits you can watch well, even in a great city. You must often have seen the starlings flying home towards evening in flocks through the sky: they are coming back from the fields to sleep in the warm shelter of the town, and there they have their special sleeping-places, where hundreds and hundreds spend the night together. I do my work in London near one of the favourite sleeping-places of the starlings that feed in the fields of the home counties. And in the autumn, without looking at my watch, I can tell approximately what time it is in the late afternoon by the tremendous whistling and chattering and squawking the starlings make on the roof outside my room as they come home punctually and settle down in rows for the night.

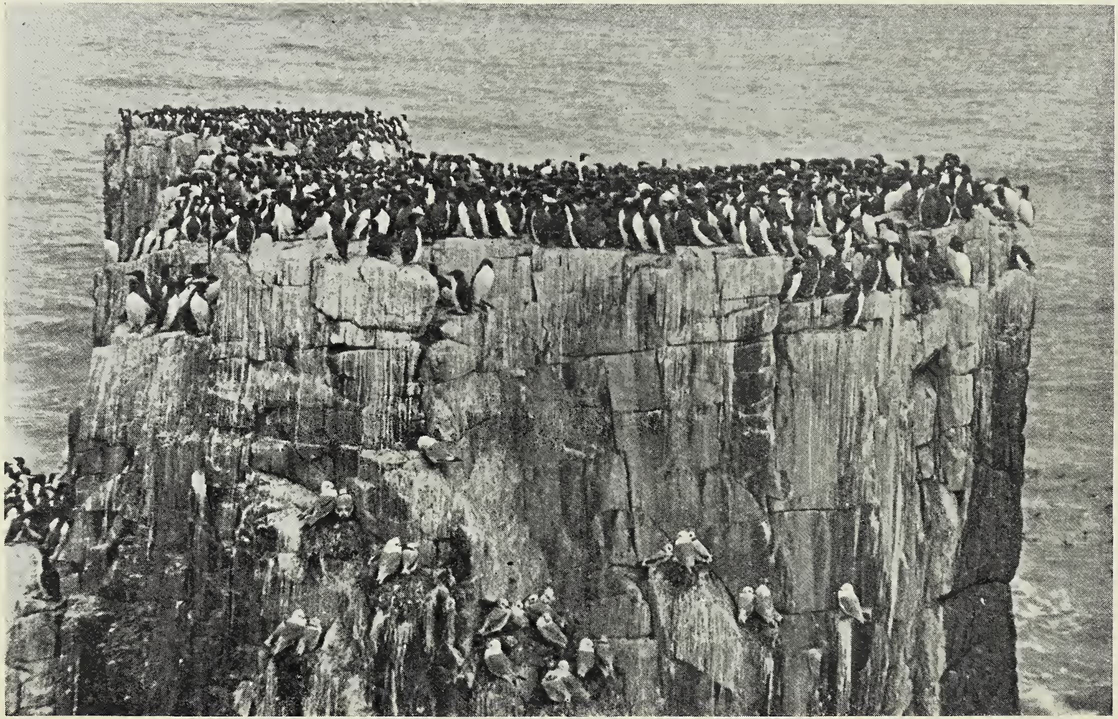
Perhaps the most extraordinary assembling of birds happens when the sea-birds like gulls and gannets and puffins are at their breeding-season. Enormous numbers of these beautiful creatures come together to make their nests and lay their eggs and then bring up their young in company. They choose the shores of some remote island, or else some wild rocky coast where they will be safe from disturbance. And for a time, you can scarcely see the ground for them and their nests, there are so many.

When I was talking about the family life of mammals just now, I took the cat as an example. For that is quite a good instance of an animal family that lives just for itself in the wild state. The father and the mother



Photo, Capt. C. W. R. Knight

A rookery.



Photo, Peter Webster

Sea-birds at the nesting season.

wild-cat and their kittens have a safe home in some cave in the mountains: and from this dark, safe home, the parents go out at night to get food: at first the kittens feed on their mother's milk, but later they must have meat. It would be just the same with the bigger, fiercer kinds of cat, too – tigers and leopards, for instance: each family lives by itself in some safe den. But some wild mammals band themselves together into a tribe, just as savage men do. A pack of wolves is what you might very well compare to a tribe of savages hunting together and sharing the food they capture.

Photo, J. J. Newman

Family of Barbary sheep.

Generally one old wolf, full of experience and cunning, leads the pack, just as a chief among the savages guides the tribe and tells them what to do. And in these wolf-packs and jackal-packs there will be some told off to act as sentinels while the others are resting; and these keep guard, so that the sleeping ones shall not be taken by surprise.

It is generally for safety that animals band themselves together into a tribe. You notice this best with animals that live on plant-food, and especially with those that graze: they have to come out into the open country to get the grass, and there they are very easily seen by the fiercer animals that are meat-eaters.

✓Families of wild sheep, for example, band themselves into what we call a flock. Families of wild horses, or of zebras, or of antelopes and buffaloes, band themselves into tribes that we call herds. The strongest, finest males are usually the ones put in charge of the herd: they are the chiefs of the tribe, and they must lead the others to the feeding-places and to the water-holes. Some keep a sharp look-out while the families of the herd are browsing or drinking, and, if danger is near, they give the alarm, or they fight off the enemy if it is too late to escape by speed. Most of these animals have several wives – like the cock among the birds – and that is one reason, no doubt, why the bull is large and powerful and why the ram has those great horns for fighting weapons. The females are usually smaller and less fierce than their mates, though they can be very savage indeed if their young are threatened. The duty of the females in the herd is not so much fighting as looking after the young ones and giving them milk if they are too young to crop grass. The mother sheep, the ewe, sees to it that her lambs do not go straying far from the flock into dangerous corners where wild beasts may be lurking. Directly she sees her young straying away, the mother gives a special kind of bleat, and they come running back to her obediently and are safe in the flock.

CHAPTER XXXVI

HOW ANIMALS LIVE TOGETHER (ii)

LIFE IN A COMMUNITY – THE HIVE – THE COMB – HONEY-GETTING – BEES' BREAD – WAX-MAKING – THE NURSERY – THREE TYPES OF BEE – THE BEES MAKE THEIR OWN QUEEN – JACK-OF-ALL-TRADES – BUT MASTER OF EACH IN TURN – LIVING RADIATORS – AND VENTILATORS

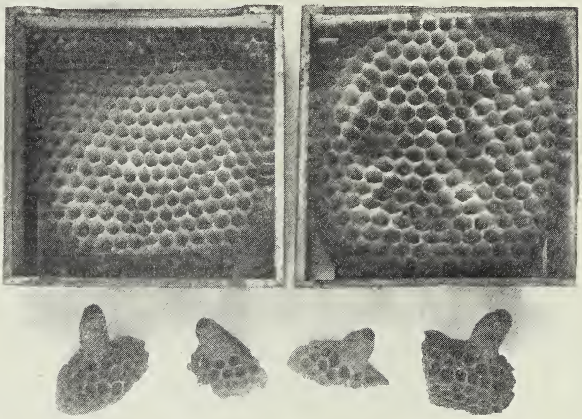
THIS chapter is about bees.

But first, I want you to imagine a large village of people, where every family lives entirely on its own. You are to imagine each family keeping its own cows, and growing its own corn, and building its own house, and making its own clothes and boots. That would be one way of living together in the same village: but it wouldn't be a very sensible way. For each family would have far too many things to do, and probably none of them would be very well done. Surely it would be a much better arrangement if the people were to divide up the work between them – some of them looking after the cattle for the whole population, some of them doing nothing but grow the corn and potatoes, some of them making the clothes for all the others as well as for themselves, and some of them making all the boots and shoes. There would be a division of the work: each batch of people would choose the thing they were best at doing and they would get very skilful at it: and everybody in the end would get the benefit. That, of course, is what happens when human beings live together in a village.

Now the bees live together in very populous bee-villages, and they have hit upon this idea of dividing up the work between them.

When you are in a garden in the summer, watching the insects on the flowers, you may notice several kinds of bees. But the kind I am thinking of just now is the honey-bee. In a wild state, these insects live in hollow trunks of old trees and in places like that. But man has turned the honey-bee to his own use, as he has turned cattle and horses to his own use; and he gives the bees special places to live in, sometimes made of straw, but nowadays usually made of wood. The bees find these places very convenient and are quite pleased to live in them.

Inside, the hive is very dark, and here in the darkness the bees stay quietly in the winter, all together, living on the stores they collected the previous summer. They work so hard in summer that they collect far more than they require really, so there is always plenty of honey left over for the man, in exchange for the place he has given the bees to live in. The special store-cupboard for the honey is a most wonderful structure called the comb, all made of delicate white wax. There is a picture on this page showing bees' combs built in the wooden frames which the man fits up inside the hive. The comb is made up of hundreds and hundreds of little pots or 'cells' of white wax, pressed together so that they have a six-sided shape. When the bees have filled a cell with honey, they put a lid of wax on top to keep the air out – just as we seal up the jam-pots when we have made jam and are going to put it in the store-cupboard for the winter.

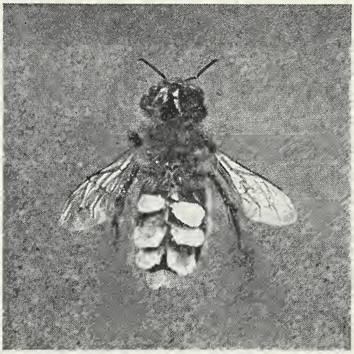


Photo, H. Bastin

Combs of the honey-bee. Left, a worker comb; right, a drone comb; below, four queen cells.

Honey is made from a sweet sticky stuff called nectar which the bee sucks up from the inside of a flower; and gradually she fills with it a little bag she carries in her inside. Within this bag the stuff is changed into what we call honey. Suppose the bee is working on clover: she will have to visit 1,000 clover flowers before she has collected a drop that will fill her honey-bag and can go back to the hive with it. Here she is met by a younger bee, and this second bee takes the honey from her and runs with it to the comb, where she pours it into one of the pots. There is no more than a drop each time; but the bees work so hard that a good-sized hive will collect as much as ten pounds of honey in one day, drop by drop. The honey, being mainly sugar, is a splendid food for giving energy: and bees are such energetic creatures that they need a very large amount of sugar to keep them going, especially in the summer when they are flying and working. But no creature can live long on sugar and water alone. There must be something else as well – something for body-building, something to take the place of meat or cheese. Some protein, in fact. Now we find this food, this protein, stored in some of the pots of the comb. It is called bees' bread. It is a yellow, solid, very nourishing stuff; and it is all made from the pollen of the flowers. The bees collect this powder from the flowers, and then knead it into bees' bread and store it in some part of the comb.

But the wax for making the comb comes from their own bodies. Look at that bee in the picture. We are looking at its underside. Do you notice these white things like six little plates ? This is the wax stuff oozing out through the bee's skin, and as it hardens in the air and the plates get larger, the bee snips them off and squeezes them, as you would squeeze plasticine, into the shape she wants for a honey-pot in the comb.



Photo, H. Bastin

Bee making wax for the comb. Notice the white plates of wax on the under side of her body.

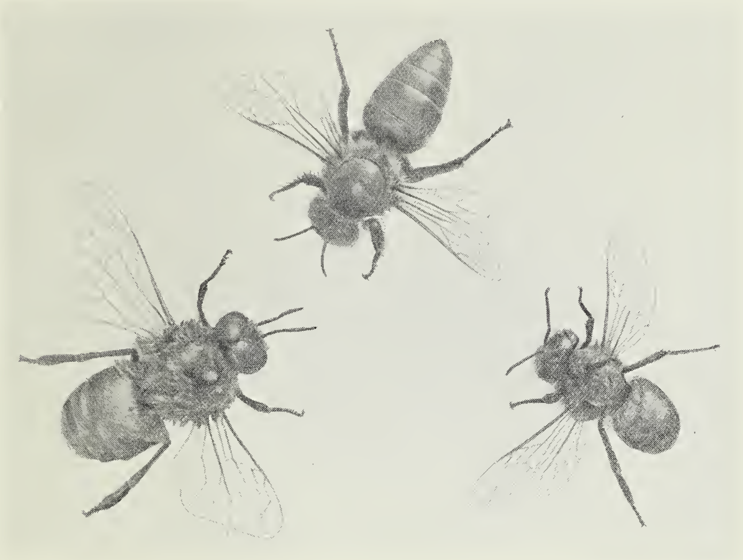
Although a lot of the comb is used for storing food, some of it is kept for nurseries. In these combs the cells are cradles for the young. One egg is laid in each cell, and at the end of three days there comes out of the egg a small white grub. The bees then feed these grubs: they feed them first with honey and with a special bees' milk from inside their own bodies, which they pour down the babies' throats. When the grub is a little older and its digestion is stronger, they give it bees' bread. The grub takes only six days to grow to full size. Then the bees put a wax lid over the cradle, and the resting grub turns into a chrysalis or pupa. About twelve days later the perfect young bee with wings eats its way out through the lid of its cradle. And at once this new bee is able to take a share in the life of the village.

Just look again, will you, at those combs on p. 246. Do you notice that the cells in the right-hand comb are larger than the cells in the left-hand one? And do you see these four thimble-shaped things below? These are three sizes of cradle to suit three sizes of bee. There are actually three sorts of bee in the hive, and they are brought up differently in different parts of the nursery.

The three sorts of bee are shown in the picture on p. 249. The one at the top has a long, pointed body. The one on the right is smaller, and is shorter behind. The bee on the left is big, its body is broader, and its eyes are larger in proportion. The honey-bees that you see most commonly on the flowers are like the ones on the right side of the picture. They are called the workers; and it is certainly a good name for them, for they do practically all the work in the bee village. The long-bodied bee at the top is called the queen bee. She lays all the eggs, and so she is the mother of all the others. The queen bee does nothing but lay eggs and eggs and eggs, one into each cell of a nursery comb. A group of workers always surrounds her, telling her what to do and feeding her very richly. Unless she leads a swarm, the queen seldom leaves the darkness of the hive: but once in her life every queen flies out and high up into the air to meet the male bee who is to be her husband. After that, she comes quietly back to the hive and sets about egg-laying. She lives a long time for an insect – as much as five years, I believe.

The third kind of bee is the male – that one on the left, with the larger eyes. One of these males is to be the queen's husband; and with his great bright eyes he spies her out when she flies from the hive, and he follows her up into the air for the wedding. Otherwise the male bees do very little to help in the hive. They don't collect honey and they haven't even got a sting like the workers, for killing enemies with. In winter the males would eat up too much of the honey store without giving services in return; so when autumn comes, the workers kill the male bees – the drones, as they are called. Next season they rear a new brood of drones, when food is abundant again.

Now perhaps you begin to see why there are these three sizes of cells in the comb where the eggs are laid. The small cradles are for the grubs that will turn into workers: the bigger cradles are for the ones that will be the males: the thimble-shaped cells are for the few, precious eggs that will turn into queens. These are called the royal cells. There must always be a few queens got ready, in case the old queen should have an accident and die. For if the queen died, there would be no eggs laid, and soon the bee-community would come to an end. . . . Here's another interesting thing. The eggs that will give queens and the eggs that will give workers are exactly alike. But the grub in the royal cell is fed much more richly than her sisters and she has much more room to grow in: it is this extra food and extra space that make her turn into a queen instead of into a worker.



Photo, F. Martin Duncan

The honey-bee. Queen, above; drone, left; worker, right.

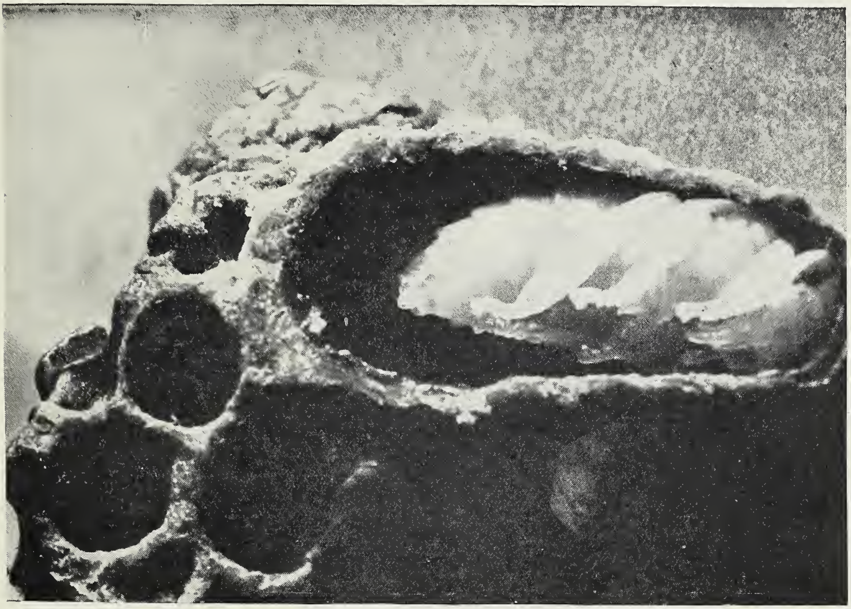
The worker's life is short. After she leaves her cradle, she lasts, on the average, about five weeks. At the end of that time she is quite tired and worn out, and she dies of old age. Most observers agree that she begins to work almost at once, and never stops working until she dies. But it is a very interesting, varied sort of life: she is not kept sticking to one job all the time. There is a regular programme. First she is a housemaid; for three days she does nothing but clean out the old cradles and get them ready for a fresh batch of eggs. Then she is promoted to become a nurse, and she remains a nurse for about seven days. At first she gives the older grubs their honey and bees' bread; later on, she does the more difficult job of feeding the younger grubs with bees' milk. Then, when the worker is ten days old, she is put to another trade. She comes down near the door of the hive and she acts as a porter: it is her duty now to take the honey from the bees that come in and carry it to the combs to be stored. And at this time she also acts as a mason: wax plates exude from her body and she does her share of comb-building.

When she is about eighteen days old, she joins the brigade of sentinels. The sentinel bees are posted at the door of the hive – inside and outside it – and they have to decide who is to be allowed to come in. With their antennæ they touch and smell the entering bees, and if these bees can't give the pass-word of the hive, the sentinels push them out, or even kill them and throw the bodies out. Sentry-go lasts for three days. But already while she is on guard duty, the young worker begins to take short flights from the hive, and gradually she gets to know the country near by, so that she is not so likely to lose her way later on when her turn comes to go out for honey.

And now at last, when she is three weeks old, the worker is promoted to the highest grade, and she becomes a collector of honey and flower-dust. She has to fly far afield to look for the best flowers. She gets to know her way about the countryside, and very seldom do bees get lost. No one can tell exactly how it is that the bee finds her way so surely. Probably she depends a lot on her good eyesight, and on her excellent memory for what she has once seen. In foreign countries especially, the beekeeper paints his hives in different bright colours, and this is a help to the bees in distinguishing their own particular home when they come back.

There are days, of course, even in summer, when the weather is wet and chilly. Then you don't see bees in the garden. They are in the hive, and crawling about over the nurseries in great swarms, warming the grubs and the eggs with the heat made by their close-packed, moving bodies. This is where the drones do help to some extent: in a hive containing many of these richly fed males, the heat produced may be very great. This warmth is important, because, if the temperature in the hive falls below 93 degrees, the young will not develop properly. The heat must not be too great, though. So, if the day is very hot, you find that certain of the honey-gatherers remain in the hive to act as – ventilators! They sit together in crowds near the entrance and fan the air very rapidly with their wings, so that a cool draught blows through the bee-village, and the temperature, which was mounting dangerously high, drops again to 93 degrees.

Please notice that the bees are never taught one single thing about how to do these very different jobs. From the moment she has wings, the worker bee knows just what to do and does it perfectly. She hasn't got to learn her half-dozen trades: she just does them straight away, and no apprenticeship is necessary. This is a splendid example of what is called instinctive behaviour.



Photo, Alex Stöcker

Young queen bee in a royal cell.

The bee is not the only insect that has this elaborately arranged social life. Wasps also have their villages or colonies, and parcel out the duties between the various classes of wasp that live there. And, from the little I told you about ants in Chapter XXXIV, you can see that there too there is community-life on a big scale. In fact, the ants are perhaps the most interesting of all to those who study the ways in which animals live together. But to give you a notion of the complicated system the ants have worked out would take up several chapters.

CHAPTER XXXVII

THE FLOWER AND THE FRUIT

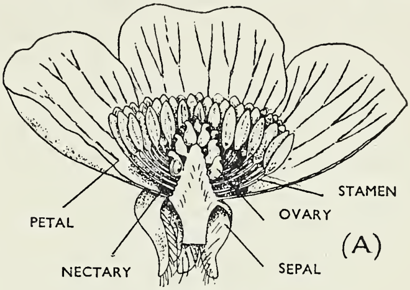
THE FLOWER IS NOT MERE DECORATION – THE PARTS OF A FLOWER – POLLINATION – FERTILISATION – THE SEED AND THE FRUIT – JUICY FRUITS – COLOUR AS ADVERTISEMENT – BRINGING THE SEEDS TO EARTH – THE VALUE OF DISTRIBUTION – PRICKLY FRUITS AND THEIR DISPERSAL – THE DANDELION-CLOCK

FLOWERS make so much of the beauty of the living world that we are apt to think of them just in that way – for the pleasure they give us by their colour and shape and scent. But it is also worth while to think of them in another way – as a part of the plant on which they grow. For the flower is not merely for decoration. It is as necessary to the plant on which it grows as are all the other parts, such as the leaves and the stem and the roots. If there were no flower, there would be no fruit.

May, June, July – these are the best months for flowers. Even in July, and certainly by August, the flowering time is coming to an end, and the time of fruits begins. Where there was white strawberry blossom, there are red, juicy strawberries in the garden: where there were pink and white flowers in the orchard, there now appear the round, green beginnings of the apple fruits: where there was pink or white may on the hawthorn trees, there are now little berries turning red. How does the flower turn into the fruit?

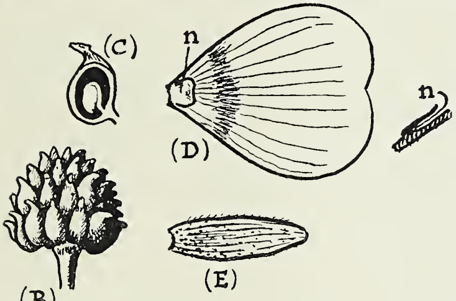
To explain something about that, I must first consider the parts of a flower and what each part is for. And I shall take a very common flower, a buttercup, as an example. The most obvious thing about the buttercup, of course, is the circle of coloured leaves that give it the shape of a shallow cup. There are five of them and they are bright yellow: on the inside especially, they are so shiny that they look as though they had been varnished, or quite newly painted. We call these coloured leaves the petals. Outside the petals are five smaller, greenish leaves, folded back against the stalk. These are called the sepals. When the flower was a bud and its petals still very tiny, the sepals completely covered them over and protected them: but now the petals have grown, the flower has opened, and the sepals are folded back out of the way.

Nearer the middle of the flower, and just inside the petals, is a sort of hedge of small things that look like pins with long heads. These are also bright yellow. They are called the stamens. These heads to the stamens are really little bags filled with coloured powder called pollen. If you rub your finger over the stamens of a full-blown buttercup, these little bags burst and the yellow powder comes out and sticks to your skin. Yellow is the most usual colour for pollen; but it may be orange or purple or blue or red. Sometimes the pollen is the same colour as the petals of a flower, and sometimes it isn't.



Buttercup cut open longways.

I mentioned pollen in last chapter, when I was telling you about bees. The honey-bees collect pollen from the flowers and take it home to make bees' bread. And they also go to the flowers for a sugary fluid called nectar. In a bag in the bee's inside the nectar is turned into what we call honey; and as honey it is either used for food immediately, or else it is stored in the comb for future use. The place where the nectar is manufactured in the flower is called the nectary. If you look at the picture above (where a buttercup flower has been cut longways so that you can see the parts inside) you will find that a nectary lies at the bottom of each petal, just outside the hedge of stamens. In the lower picture a petal has been pulled off (it is marked D), and there the nectary shows better: it is marked *n*.



Buttercup. (B) fruits; (C) a fruit, ovary, cut open to show the seed inside; (D) petal; (E) sepal; n, nectary.

From Wyeth's *Elementary General Biology* (G. Bell & Sons, Ltd.)

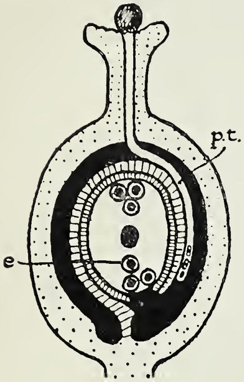
Right in the centre of the flower, in the middle of the hedge of stamens, is a little green mound with small green things standing on it. These small green things are called the ovaries; and each ovary contains a tiny egg, which may turn into a seed. On the top of each ovary is the stigma, a patch of sticky stuff. These very small parts show in the little picture (C) on last page. (C) is one of the buttercup's ovaries cut open to show the seed inside; and you notice the little knob on the top of the ovary ? That is the sticky stigma.

All this rather inconspicuous part in the middle of the buttercup is really very important, for where the ovaries are is what will eventually be the fruit. The petals wither and fall off: the stamens shrivel up: but the ovaries get larger, and the egg that lies inside each ovary ripens and becomes a seed. What we call fruit, is really the full-grown ovary with its ripe seed inside. The little picture B on p. 253 is what the buttercup looks like when its petals are gone and the fruit is formed.

I spoke of the egg being *ripe*. What exactly do I mean by that ? Although the word 'ripe' sounds very simple, what actually happens to bring that about is rather complicated: but it is so important that I must explain this part in some detail. On p. 255 is a picture of an ovary cut open to show the parts inside it: it is drawn very big to make it clearer. In that picture, the letter *e* is pointing to a small round thing which is the egg of the flower lying safely in the middle of the ovary. Then notice another round thing lying on the top of the ovary, on its stigma. That is a single grain of pollen – drawn very, very large, of course. Now, when a pollen grain falls on the stigma, it sticks to the surface; and a strange thing happens. It begins to push out what looks like a tiny root: this is called the pollen-tube, and it grows down into the ovary. The pollen-tube is marked p.t. in the picture. You can trace it down from the pollen-grain into the ovary where the egg is lying. It hasn't grown all the way down yet: but presently it would grow longer still and it would push in through a gap into the place where the egg is, and would join up with the egg. From the moment the pollen-tube has reached the egg and joined with it, the egg is ripe. We say that it has been *fertilised*. And now it becomes a seed. If the egg is not fertilised, if it is not touched by a pollen tube, it will not be able to turn into a seed: it will just die. But if the egg is fertilised, the seed develops; and if that seed be placed in the ground, a new plant will grow from it next spring.

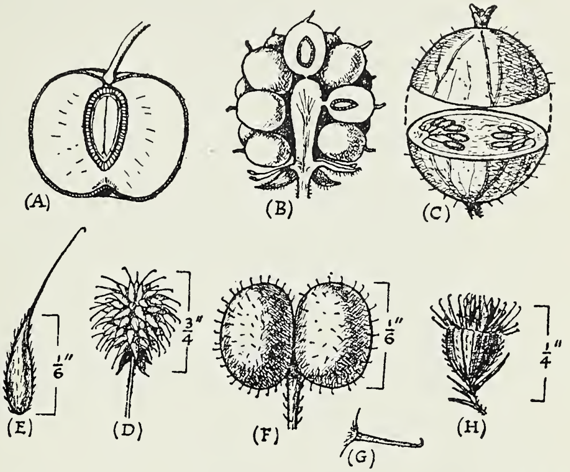
The next problem is to get the seed into the ground. After the egg has been fertilised and is a seed, the ovary that holds it is called the fruit. The fruit of a buttercup is not very large or handsome when you compare it with the flower. But in many plants the fruit is much more conspicuous than the flower from which it came, and just as beautiful in its own way.

Cherries, apples, plums and peaches are brilliant, beautiful fruits. And the plump gooseberry is actually far showier than is the small, yellowish flower of the gooseberry bush. In the picture to the right a gooseberry, along with several other fruits, is shown cut open so that you see the seeds lying inside. What we call the 'stone' of a cherry or a plum is really a seed. And what we call a coconut is an enormous seed taken out of the fruit of the coconut-palm.



Fertilisation. Ovary cut open longways. A pollen-grain has fallen on the stigma, and a tube, p.t., is growing down from it into the ovary to fertilise the plant's egg, e.

From Wyeth's *Elementary General Biology* (G. Bell & Sons, Ltd.)



Some Fruits. A, cherry, cut open longways; B, blackberry; C, gooseberry, cut open crossways; D, avens; E, part of the same drawn larger; F, goose-grass; G, one of the hooks; H, agrimony.

From Wyeth's *Elementary General Biology* (G. Bell & Sons, Ltd.)

It is things like gooseberries, cherries, apples, plums, pears and melons that we usually think of as fruits. The very word 'fruit' makes one think at once of something sweet and juicy, delicious to the taste. In all these kinds, the part outside the seed, or seeds, gets thick and soft and full of sugary fluid : it swells larger and larger, takes on lovely colours, and may give off a delicious scent. Now the colour attracts birds and other animals, so that they will come and eat. Birds love sweet fruits like cherries and gooseberries, and they have very good eyesight. They see the coloured fruits showing among the green leaves, and they settle on the branches and peck at the fruit when it is ripe. It is as though the colours were a sort of advertisement to attract the birds. But what is the good of that to the plant ? Why should the plant advertise its fruit ? Why is it a good thing for the plant to have its fruit eaten ?

Remember that the plant's seeds have somehow to get to the ground. This is where the birds help. As the bird pecks open a cherry, the seed gets a chance to fall out. Or, if the fruit is a blackberry or a strawberry, the bird may actually swallow the small seeds along with the pulp and fly away with them inside its body. The soft parts of the fruit will be digested by the bird: they are good for food. But the hard-coated seeds may not be digested. They may go right through the bird's food-canal and fall out on the ground with the rest of the undigested food from the bird's body: and so they come to earth, where next spring they can sprout.

Notice that in this way the plant's seeds may be carried to some distance. And it is to the advantage of plants that this should happen; for if too many seedlings sprouted up close to the parent, they would be so crowded together that there wouldn't be enough light and air and water for them all. Plants must be well spread out if they are to flourish. Here is a way, then, in which plants and animals unconsciously help one another. The plant helps the bird by providing fruit for food: and the bird helps the plant in return by opening the fruit so that the seeds fall out, or by carrying the seeds away and dropping them at some distance.

Many plants, however, have fruits that would be most unpleasant to eat. Many kinds of fruit are hard and green and sour and all covered with prickles. Often you find that these prickles on a fruit have each of them a tiny hook at the end. (*See* (E) to (H) on p. 255.) Have you ever walked through fields where burdocks are growing ? Or have you scrambled through a hedge where goose-grass clings to the bushes ? When you look at your clothes afterwards, you find them all stuck over with the fruits of these plants, clinging to the stuff by their hooked prickles. Now, sheep and cattle often get these burrs, these prickly fruits, stuck on their coats when they are in the fields grazing: and then, when the animals roll on the ground or come against bushes, they rub off the burrs. There in the grass, the fruit decays, and its seeds fall out into the earth, where next year they can give rise to a new crop of burdock and goose-grass. So here again is a way in which animals unconsciously help plants by carrying their seeds to good new places for growing.

One of the most interesting of the ways plants distribute their seeds has nothing whatever to do with animals' help. As this book is mainly about animals, I don't propose to go into this fully; but the chapter would not be complete without some mention of it. So I will just point out that many fruits are neither juicy nor prickly, and depend on being carried away by the wind. An example of a plant with wind-borne fruit is that commonest of weeds, the dandelion. You know the fluffy ball that one calls a dandelion-clock. This is all made of the fruits of the dandelion flower. Each tiny fruit has at the top of it a sort of parachute of fine hairs; and hanging from the parachute by a little stalk is what was the ovary, and in the ovary is a seed. The wind blows over the field where the dandelion is growing, and it blows off the little parachutes so that these go drifting, drifting in the air, often for long distances; at last they gradually sink down to earth, where they can sprout into new dandelion plants.

Photo, H. Bastin

Dandelion-clock.

CHAPTER XXXVIII

INSECTS AND FLOWERS

PETALS AND SCENTS – THE FLY AND THE BUTTERCUP – POLLINATION BY INSECTS – WHERE THE BEE SUCKS – THE HONEY-BEE'S BRUSH AND BASKET – BUMBLES AND RED CLOVER – WHY HONEYSUCKLE SMELLS SWEETER IN THE EVENING

WHEN describing the structure of a flower, I was mainly concerned with the forming of the fruit, so I dealt mostly with the middle part where the stamens and the ovaries lie. I did not say much about the petals, which make the conspicuous part of the flower. Why are these so large and brightly coloured ? They make the flower look very pretty, of course. But there is another, much more important, reason.

The brightly coloured petals make the flower show up against the green leaves, and this catches the keen eyes of insects flying past. If it is true that the bright colours of fruits that birds like to eat act as a sort of advertisement, so again here you have something of the kind. Where the insect sees the colour of flowers, it knows there will be food – pollen and nectar. It is like seeing a brightly coloured sign outside a shop with 'Tea served here' printed on it.

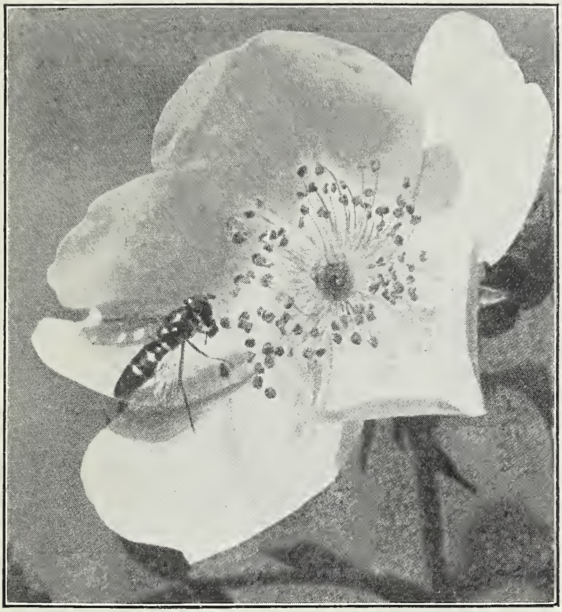
And suppose there were a good smell of food coming from the shop, a smell of cakes baking. If you were hungry, that would attract you still more as you got nearer. You would hurry in to have your cakes and tea. Probably then, that is one reason why flowers have their sweet, characteristic scents – to attract insects at close range.

There are two sorts of food that insects may find in the flower. There is the nectar, that sweet fluid stored in the little pockets, the nectaries, at the bottom of the petals. And then there is the pollen, the flower-dust, which lies in the small bags at the ends of the stamens. Nectar appeals to all flower-visiting insects: the pollen can be used as food only by such as have jaws or the right sort of tongue for eating something solid.

In the evening, when the sun sets, the petals of most flowers fold together and shelter from the cold and dew the essential parts – the stamens with their pollen and the ovaries where lie the eggs. But in the warm sunshine, the petals spread out and make a platform for the insect to alight on.

Let us suppose that the insect is a short-tongued insect such as a fly.

When the fly settles on the petal, he walks towards the middle of it where the nectar lies. As he goes, he must pass the hedge of stamens; either by walking over them or by pushing his way between them. And as the fly shakes the stamens with his body, they shed their pollen on him and it sticks to the hairs of his body and to the hairs on his legs. The fly in the picture can eat pollen, but many flies are unable to do this, and what they make for is the nectar. And their tongues are so short that they can get it easily only from the shallow, cup-shaped flowers, such as buttercups and the like.



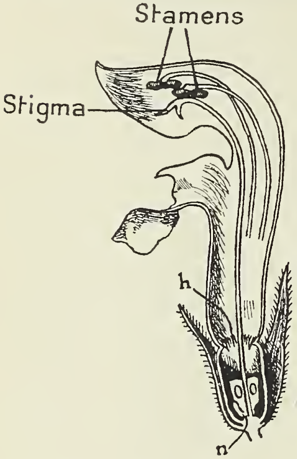
Photo, H. Bastin

Hover-fly on a wild rose.

Having had his drink of nectar, the fly goes off to another flower; and over this he also walks in search of more. But remember that his coat and his legs were dusted with pollen in the first buttercup. There is quite a good chance, as he walks over the second buttercup, that some of the pollen on his body and legs will be wiped off on to the stigma of an ovary. Now you begin to see why the flower encourages insects to visit it.

For a pollen-grain must fall on the stigma of an ovary if the egg in the ovary is to be fertilised and become a seed. This is what our fly has done for the buttercup. He has put pollen on to the stigma, and there is a good chance now that seed will set.

You might say that the buttercup could just as well curl its stamens over its own stigmas and put its pollen on them. But it is generally better for flowers, and makes better seed, if they get pollen on their ovaries from other flowers of the same kind. The pollen from one buttercup fertilises the eggs of another buttercup. The flower has helped the insect by giving him the food he needs: and in return the insect, though quite unintentionally, has helped the flower by 'pollinating' it.



Half of a white dead-nettle flower. h, hairs; n, nectary.

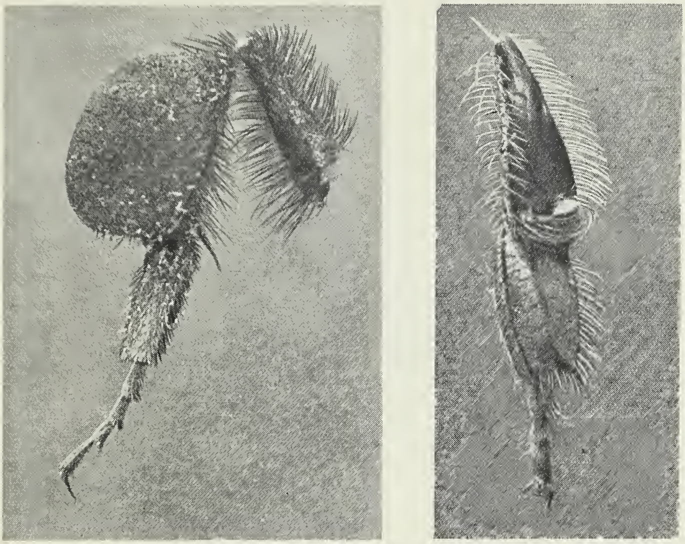
From Wyeth's *Elementary General Biology* (G. Bell & Sons, Ltd.)

All insects that go to feed on flowers are helpful in carrying pollen about in this way: bees and butterflies are perhaps even more helpful than flies. As I explained in another chapter, bees have longer tongues than flies, and butterflies have even longer tongues than bees have. So while bees and butterflies can get nectar from the saucer-shaped flowers, they are also able to stick their tongues down into the tube-shaped flowers like larkspur and snapdragon, which are no good for the short-tongued fly.

It is interesting to notice that in the tube-shaped flowers the nectar is always placed deep down at the bottom of the tube. In the picture is a flower of dead-nettle, one half of which has been cut away so that we look into the inside. At the bottom of the tube is the nectary, marked *n*, and above there are little hairs sticking in from the sides of the tube, protecting the nectary. The bee is very fond of dead-nettle nectar; but you can see that it is by no means easy for the insect to reach its food.

The bee alights on that lower petal shaped like a lip below the opening of the tube; and she pushes her head and the front part of her body in, unfolds her long tongue, and reaches down and down past the hairs until she gets at what she wants. But while she is having her drink, the stamens that arch over her back rub their pollen-bags against her shoulders, and out comes the pollen in a cloud and showers on to the bee's body. The bee has a much hairier coat than the fly, so a great deal more of the pollen sticks to her.

Now when the honey-bee draws back out of the flower, she does a thing that the fly does not do. She brushes her coat with a little brush she carries on the under side of her back leg: while she hovers in the air, with one hind-leg she brushes pollen from her coat into a basket she carries on the outside of the opposite hind-leg. Look at the photographs of a bee's hind-leg. In the one on the left you see a big lump sticking out. That lump is made of pollen which the bee has combed off her coat and packed into her basket. The 'basket' is just a slightly hollowed-out place with a fringe of bristles round the edge: the bristles curve in a little and hold the ball of pollen in place. In the photograph to the right, the leg is shown with the basket turned more towards us. The pollen has been taken

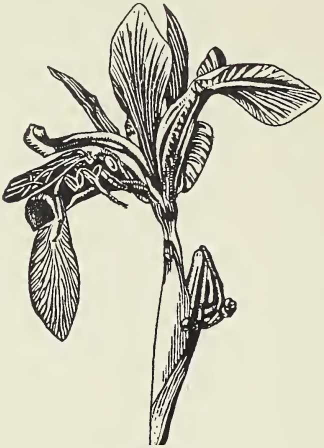


Photo, H. Bastin

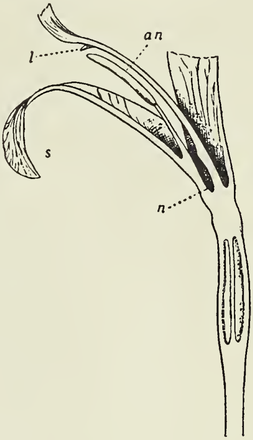
Honey-bee's pollen-basket. Left, the leg of a honey-bee with a mass of pollen attached. Right, a leg without pollen. Note how the bristles form a 'pollen-basket.'

out, and you see now quite clearly the curved bristles at the margins. When you watch honey-bees working on flowers, you will often notice coloured patches on the hind-legs. These are the baskets full of pollen. They are bright yellow, or blue, or orange, or purple, according to the colour of the pollen in the flowers the bee has been visiting: it is usual for a bee to stick to one kind of flower on each excursion she makes for honey.

The bee flies back to the hive, with her baskets full of pollen for bread-making, and her crop full of nectar turning into honey. And in the hive she hands over these food-stores to the younger bees, who then put them in the comb. Do you notice a spike sticking out from the leg just below the basket in the left-hand picture on the previous page? That is the tool the bee uses for pushing the mass of pollen out from the basket on the opposite leg when she gets home. Below that spike I can just see some hairs of the brush with which she collected the pollen off her coat.



Bumble-bee entering an Iris flower. Its back is being dusted with pollen while it feeds on the nectar.

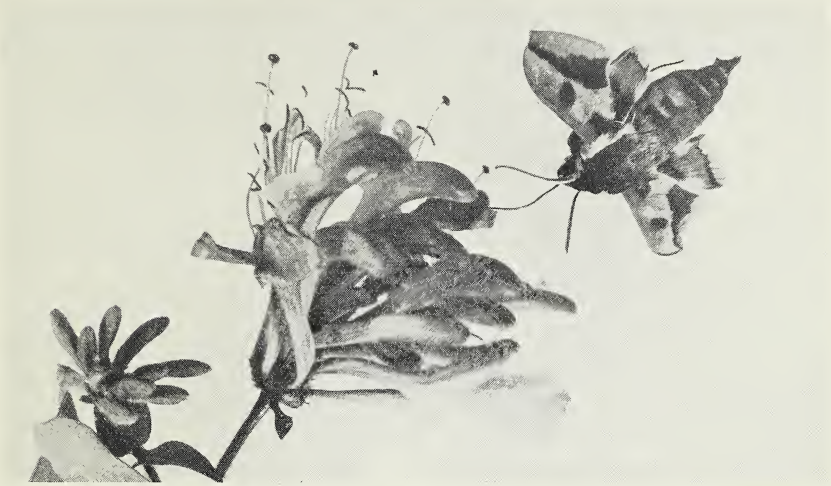


Part of the Iris flower cut longways. *s*, the sepal on which the bee rests; *n*, where the nectar lies; *an*, the place where the pollen lies; *l*, stigma.

From Folsom and Wardle's *General Entomology* (copyright P. Blakiston's Son & Co., Inc., Publishers)

But however carefully she brushes her fur, the bee does not manage to collect all the pollen sticking to it. A good deal is out of her reach, and especially on the head and shoulders. So when she goes to the next flower she is very likely to rub off some of this on the stigma, as she pushes her way in for nectar.

One of the flowers the bumble-bee is very fond of is the red clover. There is a great deal of nectar in clover, as you know if you have ever picked off the little clover-flowers and sucked the ends. When Englishmen first went to New Zealand, there was no red clover growing in that country. They wanted it for fodder for their cattle, so they had seed sent out to them from England. The first crop grew all right: the climate suited it and the earth was very rich. But it set no seed worth mentioning: and, if there is no seed, a plant like clover will soon die out. So next year the farmers had to get more seed sent from England, and start all over again from the beginning. Again there were abundant clover flowers; but again they set very little seed. Now what did that mean? The farmers were much puzzled. Then someone pointed out that there were no bumble-bees in New Zealand. So they tried an experiment. They had a whole lot of live bumble-bees sent out to them on a ship from England; and in New Zealand they set the bumbles free to feed upon the clover crop. And sure enough, that year there was some seed. And when the bumbles



Photo, H. Bastin

Hawk-moth drinking nectar from honeysuckle. Note the tongue extended; it shows between the antennæ.

had been in the country for some years and had had many, many families, so that there was a good bumble population, there was never any more trouble about the clover crop setting seed. For the bees, in the course of their nectar-getting, now pollinated the red clover in New Zealand as they do in England. That is just to show you how necessary to the plant is its right visitor among the insects.

Butterflies visit many of the same flowers that flies and bees are fond of. But they have such long tongues that they can also suck up nectar from the very long-tubed flowers like honeysuckle and Buddleia. The bee's tongue is too short to reach the nectar in the honeysuckle; but the butterfly and the moth have no difficulty. You have noticed how much stronger the scent of honeysuckle becomes towards evening ? That is to attract moths. When moths are flying, the light is so poor that they have to depend on their sense of smell more than on their eyesight for guiding them to where the flowers are. So butterflies pollinate honeysuckle in the day-time, and moths pollinate it in the evening. Some flowers do not open properly or begin to smell sweet until night is coming: I am thinking of the tobacco-plant and the evening primrose, for instance. Such plants depend entirely on moths for pollination and for the setting of their seeds that follows.

CHAPTER XXXIX

PARTNERS

FROM what you have read in this book, you will see why, though the title is *The Animal's World*, I have said not a little about plants. Without plants there would be no world of animals at all, for there would be nothing for them to feed on. Then, there would be far less available oxygen for them to breathe, the air would be intolerably dry, and there would be little shade. These are some of the general ways in which plants make animal life even possible.

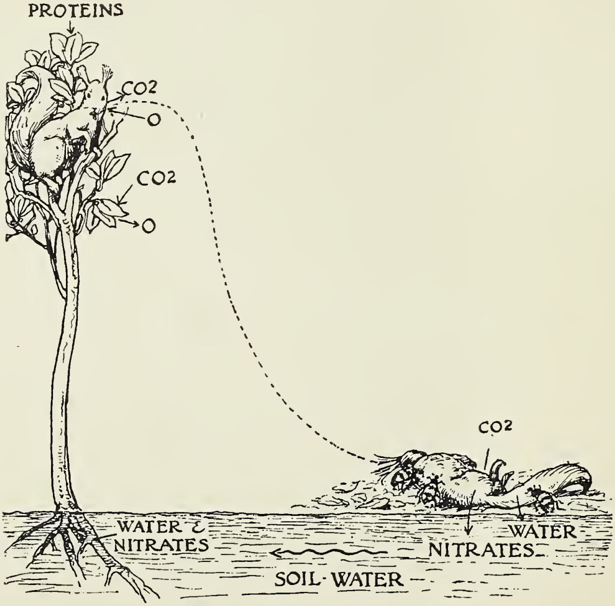
And when you consider the way of life of individual kinds of animal, you see how closely it is linked up with that of certain kinds of plants. The extinction of the flowering plants would soon be followed by the disappearance from the animal world of every butterfly and every bee. If the grasses failed, all sheep, all cattle, all antelopes, all horses, zebras and their kind would perish, for their teeth and stomachs are not suited for any other food. Or if the great trees were all cut down, not only the food, but also the natural place of shelter for innumerable kinds of animal would automatically disappear; and many of these would be quite incapable of moving about and fending for themselves upon the ground, so dependent have they become on trees.

The animals' world is made for them by the plants.

But I have said enough, even in these short chapters, to show you that the benefit is not all one-sided. It is true that plant life is not dependent on animals to anything like the extent that animal life is dependent on plants. Probably there was quite a good growth of plants on the Earth before animals became of any importance at all. But plants could never have reached their present luxuriance, variety and distribution without the animals' help. As we have seen, animals in the course of their active lives greatly enrich the air with their waste gas on which the plant can thrive; and the fluid and solid waste from animals' living bodies, together with the materials of these bodies when they are dead and in decay upon the ground, immensely increases the food-making supply at the plants' disposal. There is a constant circulation – from plant to animal, and back again from animal to plant – of the indispensable ingredients of all living matter.

On the more special side, again there is the 'give' as well as the 'take.' Indirectly, in the course of its feeding, the earthworm benefits the plant to a degree impossible to estimate. And if there were no insects to visit the flowering plants, all the most beautiful of these would disappear, since they would cease to be fertile. These are only two examples. The men who study such things keep on discovering more and more of these close interdependences.

So, in a way, you may say that the animal and the plant are partners. By this I do not mean that they are deliberately helpful to one another: the partnership is unconscious. But it is none the less real. And it is a thing that human beings would do well to remember – even if only for their own convenience. For ignorant meddling with the interwoven animal and plant worlds has sometimes cost man very dear.



The circulation of matter.

From the pamphlet for Term I 1931 for Science Broadcasts to Scottish Schools (B.B.C.)

INDEX

Abdomen, 19, 55, 60, 84, 85, 90
Adam's apple, 145. *See* Voice-box
Aeroplane, 37, 208
Air, composition of, 58, 92, 95 (*see also* Breathing); travelling in, 36; temperature of, 105
Air-sacs, of bee, 73; of bird, 38, 64–65, 74, 112
Air-tubes, of insect, 73–74, 76
Alimentary canal, of earthworm, 132; of human being, 85–90. *See also* Digestion
Alligator, 212
Animal, as apparatus, 9; definition of, 8; compared with plant, 6, 91; dependence on plant, 96, 265; helps plant, 96, 256, 265
Ankle, 15, 18, 20, 24, 27, 47, 49
Antelope, 129, 165, 180, 243, 265
Antennæ, organs of smell, 152, 167, 250; of taste, 169; of touch, 144, 151–152, 167, 250
Ants, antennæ, 144; care of young, 233–235; cold-blooded animals, 122; eggs, 235; language, 151; queen, 236; social life, 251
Ape, 197
Apple, 252, 255
Aquarium, 67, 72, 76
Armour, of insect, 14–15, 196; of man, 196
Arm, of man, 16, 18, 20, 24, 26, 32; of bat, 42; of bird, 38, 44, 47
Arteries, 10, 61

Baby, 4, 20, 135, 146, 199, 202
Back-bone, 17–19, 31, 50, 55, 60, 70, 191, 199
Balance (balancing), 20, 30, 45, 47, 137, 153, 158, 162, 193
Bananas, 203–204
Bark, of tree, 118, 126, 209, 211, 222
Bat, 36, 42, 151, 160
Beak, 127, 213, 215, 221
Bean, 8, 80, 102–104, 214
Bear, its winter sleep, 77, 120
Bee (Hive-bee), activity of, 72; breathing of, 73; care of young, 234, 247; castes, 248; coat, 262; dance, 152; instinctiveness, 202, 251; legs, 261; length of life, 248; pollination by, 260; sense of sight, 166, 185, 250; smell, 166, 250; social life, 245; tongue, 136, 260, 264
Beetle, 14, 42, 74
Berries, 82, 252. *See* Fruit
Biceps, 16
Bird, activity, 64, 206; air-sacs, 38; breast-bone, 37, 45; brooding, 206, 222; compared with insect, 72, 235; colour, 207; crop, 224; dispersing seeds, 256; eggs, 208, 212, 220; feathers, 40 (*see* Feathers); feeding young, 223; flight, 36, 195, 202; food, 182, 184, 206, 208, 211, 223, 256; food-canal, 127, 256; gait, 27; instinctiveness, 202; language, 148; lightness, 37; migration, 120; muscles, 44; nest-making, 200; sense of hearing, 160, of sight, 181, 207, 222, 255, of smell, 166; skin, 112; tail, 40; temperature, 108, 112; toes, 27, 47; voice-box, 149; warm-blooded animal, 108, 110, 120; wing compared with human arm, 38
Blackbeetle, 73–74. *See also* Cockroach
Blackbird, 148, 207, 222, 224, 239
Blood, 10; as carrier of food, 11, 81, 88, 172, of heat, 11, 106, 109, of gases, 11, 60, 64, 66, 68, 70, 215, of waste to kidney, 11, 89
Blood-vessels, 10–11, 59–62, 66, 70–71, 85, 89, 109–110, 172
Boa-constrictor, 55
Body-building, 81, 214, 247
Bones, air-filled, 37; as food, 126; as inside skeleton, 17; composition of, 14; development of, 81; of bird's leg, 47, shoulder-girdle, 45, wing, 38; of dog's skeleton, 20; of ear, 157, 194; of horse's leg, 21; of human skeleton, 17; of skull, 18, 158, 194; of whale's fin, 32
Bracken, 165, 206
Brain, as control, 12, 18, 77, 89, 114, 140, 158, 160, 171, 174, 176, 183, 190; of earthworm, 199; of insect, 183, 199; seat of feeling and thought, 192, 194; structure, in human being, 193, in other vertebrates, 197
Bread, bees', 247, 253; foodstuffs, 80, 87–88; its smell, 189
Breast, of bird, 44–46
Breast-bone, of bird, 37, 45; of human being, 19, 45, 60; of other mammals, 64
Breathing, by bird, 64; by chick in egg, 215; by earthworm, 70; by fish, 68, 236; by frog, 66, 68, 235; by human being, 59, 191, 193; by insects, 72, 229; by other land-mammals, 63; by plants, 63, 92, 93; by seeds, 102; by snails, 70; by tadpole, 66, 218, 235; by whale, 32, 63; what it is for, 59
Bristles, 52, 144, 261–262
Brood, 201, 225, 232–233, 248
Bud, of potato, 100, 119; of tree, 118–119
Buffalo, 205, 243
Bulb, 101, 121
Bumble-bee, 122, 263–264
Burning, essential for life, 57; of candle and coal, 57; of food in the body, 58–60, 80–81, 105
Burrows, 51, 130–133, 205, 220
Butter, 80, 84, 88, 105
Buttercup, 259–260
Butterfly, conversation, 238; ears, 154; eggs, 219, 238; eye, 187; pollinating honeysuckle, 264; sight, 184–185; tongue, 136, 260, 264; wings, 42; young, 229, 238

Caddis-worm, 75–76
Camel, 26, 77, 82, 129
Camera, eye as, 171, 174, 182
Camouflage, 208. *See* Hiding
Cane-sugar, 88, 89
Carbohydrates, 78, 80, 89, 92–93, 95, 99, 117, 123–124
Carbon, 59, 78, 80, 92–93
Carbon-dioxide, 59, 62–66, 68, 76, 92–93, 116, 193, 215
Carnivore, 78, 80, 123, 129
Carrot, 100, 102
Cat, brain and nerves, 140; carnivore, 82, 123, 180; digestion, 84; eyes, 176, 180; family life, 239, 243; favourite food, 124; feet, 23; intelligence 204; language, 146, 225; living being, 1; mother, 4, 126, 146, 225, 239; need of oxygen and fuel, 2; repair and growth, 3; sensitiveness, 6; tongue, 126, 225; teeth, 124, 126; whiskers, 1, 10, 143

Caterpillar, 156, 184, 208, 212, 219, 223, 229, 238
Cattle, chew the cud, 129; dependence on grass, 265; distribute seeds, 256; domesticated animals, 226, 245; prey of wolves, 226
Cell, of bee's comb, 246–249
Cerebellum, 193, 197, 199
Cerebrum, 193, 197, 203
Chaffinch, 223–224
Cheese, 80, 91
Chest, 19, 55, 59, 65, 85, 149, 191
Chewing, 86; the cud, 128
Chicken (chick), 148, 207, 222, 239–240; development in egg, 212–216, 218
Childhood, of birds, 225; of insects and frogs, 228–236
Chimpanzee, 197
Chrysalis, 231, 247
Circulation, of blood, 62; of matter, 265–266
Claws, 9, 21–22, 50, 196, 205, 229
Clothes, animals', 110; colour of, 205; heat-holding, 106, 110, 196; invention and making by man, 196
Clover, 114, 246, 263–264
Coal, 2, 57, 93
Cock, 239–240
Cockroach, 14. *See* Blackbeetle
Cocoon, of ant, 235; of silkworm, 230
Cold, effect on appetite, 110, on earthworms, 133, on plant, 116, 119; in the head, 163, 169; sensitiveness to, 141–142, 222
Cold-blooded, 107, 117, 121–122
Collar-bone, of bird, 45–47; of human being, 18
Colour, advertisement, 255, 258; appreciation of, by birds, 182, by insects, 185, by human beings, 175, 186, by monkeys, 182; disguise, 205; of birds, 207; of birds' eggs, 208, 220; of flowers, 252, 258; of leaf-insect, 209; of stick-insect, 211
Colour-blindness, in animals, 182, 185; in human beings, 175
Comb, of honey-bee, 246, 250, 253, 262; cat's tongue as, 126; fish's gill compared to, 68
Contraction, 15, 17, 46, 52, 60, 88, 145, 190
Control, of body's working, 12, 17, 191, 200; of pests, 224
Conversation, of ants, 151; of butterflies, 238; of grasshoppers, 150
Cork, formed by tree, 116, 118
Corn-seeds, 87, 127, 204, 245
Cow, hoof, 22; milk, 227; shape of body, 124; smell of body, 165; stomach, 128
Crab, skeleton, 14; ears, 154
Crawling, of earthworm, 50; of snail, 54, 70; of snake, 54
Crocodile, 24, 55, 180–181
Crop, 224, 262
Curlew, 208, 220

Daisy, feeding, 91–92
Dandelion, 123, 228, 257
Decay, 95, 133, 265
Deer, 129, 165, 181, 195, 206
Dependence, of animals on plants, 96; of kitten on cat, 225
Dew, protection from, 114, 258
Diaphragm, of eye, 171; of mammal's body, 60, 64–65, 71, 77, 85, 191
Diet, 81–82, 123, 236
Digestion, by bean-seedling, 103; by birds, 127–128, 223; by earthworm, 132–133; by grub of bee, 247; heat produced, 106; what it is, 85
Digestive juice, 87, 127, 133, 191
Digits, 21–23, 27, 42
Dog, behaviour, 198, 204; brain, 198; coat, 110; colour-blind, 182, 185; cooling itself, 112; eyes, 176; feet, 20, 23, 26; hunting, 164, 205; intelligence, 112; lips, 147; running, 26; sense of hearing, 147, 158, 164, 182, of smell, 139, 163, 182, 222; skeleton, 20; teeth, 125
Dormouse, its winter sleep, 77, 120
Dragon, antiquity, 37, 42
Dragonfly, 42, 76, 185, 187, 232
Drone, male bee, 248, 250
Drowning, 63, 67
Drum (Ear-drum), 140, 154, 157–158, 160, 162, 189–190, 194
Duck, 34, 239
Duckling, 222, 226

Eagle, 37
Ear, of bird, 160; of cat, 140; of frog, 160; of fish, 162; of invertebrates, 154; of jelly-fish, 153, 162; of man, 137, 157, 189, 194
Earthworm, abundance, 51, 130; brain, 199; breathing, 70; burrow, 51, 130; cold-blooded, 107, 122; crawling, 50; food, 132; helpful to plants, 133, 266; prey of birds, 130, 132, 184, 223; shape, 51; skin, 52, 70, 144, 184; softness, 14
Egg, compared with seed, 8, 102, 212, 253; food-stuffs, 80, 214, 232; need of warmth, 113, 206, 215, 218; number, 222, 239; of bee, 247; of bird, 206, 208, 212, 220; of frog, 217; of insects, 218, 232; size, 216, 218
Egg-shell, 213. *See* Shell
Elephant, 26, 91, 123, 136, 178
Embryo, 213. *See* Life-spot
Energy, 58, 64, 80, 105, 231, 247
Engine, of the body, 74, 122; of a car, 189
Evergreen, holly and pine, 118
Excretion, organ of, 10
Eye, of bird, 181; of human being, 170, 189, 196; of insect, 183; of potato, 99; of snail, 184; of vertebrates, 176; position on head, 174, 178; sense-organ, 137, 170; size, 178
Eyebrows, 170
Eyelids, of animals, 114, 140, 177; of human being, 170, 177, 189, 191
Eyesight, 139, 166, 255

Family (Family life), of birds, 220, 222, 224, 239–240; of bumble-bees, 245; of furry animals, 239–240, 244; of human beings, 237–238, 245
Farmyard (Farm), 216, 226, 239
Fat, digestion, 85, 89; food-stuff, 80, 123, 214; heat-giving value, 81, 105, 110, 214; manufacture by plant, 96; seal's, 110; stored in body, 77, 120, 122
Feathers, as clothes, 110–112, 196; as lining of nest, 221; colour, 206; of head, 160; of leg, 47; of wing, 39; of young bird, 207, 213, 222, 224; structure, 40
Feeding, by animal, 91–92; by plant, 91–96, 116–117
Feelers, 144
Fertilisation, what it means, 254
Field-mice, 96, 120, 143
Fins, of fish, organs of locomotion, 30–31, of sense, 169
Fish, brain, 198; breathing, 68–69 (*see also* Gill); ear, 162; extra sense-organ, 139; eyes, 177, 182; fins and tail, 30–31; scales, 31, 236; sense of smell, 166, of taste, 169; shape, 28–29; swimming movements, 30; temperature, 107
Flesh, 15, 44, 78, 124, 126, 219
Flesh-eater, 78, 96, 119, 123, 206, 226, 243
Fliers, 36, 42
Flock, 243–244
Flower, colour, 252, 258; scent, 164, 166, 252, 258; shape, 260; spring, 101; parts of a, 252–254; potato, 98, 100; value to plant, 252–254; visited by insects, 246, 258, 266
Flower-dust, 72, 166, 250, 258

Fly (*see also* House-fly); activity, 107; eye and eyesight, 185, 187; feeding, 134, 259; grubs, 229; limbs, 42, 50; pollination by, 260; prey of dragon-fly, 233, of spider, 96, 156; temperature, 107; walking on ceiling, 50; wings, 42
Flying, 36, 40–41, 202, 225
Focus (Focusing), 171, 180, 185
Food, as fuel, 2, 7, 77, 84, 105; as material for growth, 4, 7, 97; as material for repairs, 3, 7, 78, 84, 97; composition, 78; digestion of, 84–89; of animals, 6, 78; of plants, 6, 98; of young birds, 223; of young mammals, 226; protect from flies, 135; smell, 164–167, 169
Food-stuffs, composition of, 78; digestion, 85; in hen's egg, 214; in milk, 227; manufacture by plant, 92, 101, 104, 114, 116
Foot, of bird, 27, 47; of dog, 20, 23, 26; of fly, 50; of horse, 21; of human being, 18, 23, 61; of snail, 54, 70; of turtle, 33
Frog, development, 66–68, 218, 236; ear, 160; eggs, 216, 238; eyes, 180, 236, focusing, 182; hibernating, 122; inside organs, 10; jumping, 27; skin, 66, 68, 122; swimming, 35; teeth, 236; temperature, 107, 217; voice, 149, 160
Frost, effects of, 82, 117, 122
Fruit, colour of, 182, 255, 258; definition of, 254; food, of birds, 224, 255–256, of monkey, 182, 203; prickly, 256; scent of, 255; vitamins in, 82; wind-borne, 257
Fuel, for the body, 2, 58, 74, 77, 84, 106, 118, 120. *See also* Food
Fur, as clothes, 110, 196, 226; colour, 206

Gait, 26. *See also* Walking
Galloping, 26
Gas-bag, of fish, 31–32
Gastric juice, 88
Geranium, 4, 5, 7
Gill, of fish, 68–69, 235; of tadpole, 66–67, 236
Girdle, hip, 18; shoulder, 18, 45
Gizzard, of earthworm, 133; of hen, 127–128
Gliding, by tropical squirrel, 36
Glucose, grape-sugar, 87
Goldfish, 29–30, 68, 177
Grape-sugar, 87, 89
Grass, as food, 82, 124, 128, 178, 244, 265
Grasshopper, 150, 154–155
Gristle, as inside skeleton, 14; of larynx, 145
Grub, 218–219, 229, 235, 247–250
Gullet, 53, 85, 87–8, 127–8, 224

Haddock, 68–69, 139
Hairs, of mammal, as coat, 110; sensitiveness, 142–144; sprouting from skin, 40, 141
Hand, of bat, 42; of bird, 39, 41; of dog, 20; of horse, 21; of human being, 16, 22, 24, 26, 190; of monkey, 180; of rabbit, 26; of turtle, 34
Hawk, 148, 181, 207–208, 222
Heart, 11, 17, 60, 77, 191, 193
Heat, effect on frog's egg, 218; form of energy, 58; from activity of muscles, 105, 250; from burning food, 81; from sprouting bean-seeds, 104; from rusting of iron, 57; in bee's hive, 250; in bird's nest, 221; loss in evaporation, 106, 109; loss from surface, 107; sensitiveness to, 141
Heel, of bird, 48; of dog, 20; of man, 23; of rabbit, 23
Hen, alimentary canal, 127–128; behaviour, 204; egg, 212–215, 220, 222; family life, 239–240; third eyelid, 177
Herbivore, 80, 82, 123
Herd, 165, 206, 243–244
Hibernation, 120
Hiding, from enemies, 205–211
Hive, 186, 245–248, 250, 262
Honey, 78, 152, 246, 250, 253, 262
Hoof, 22, 165
Horn, of snail, 54, 144, 184; as outside skeleton, 14, 50; as weapon, 205, 244
Horse, broken-kneed, 24; coat, 110; dependence on grass, 265; domestic animal, 226, 245; gait, 26; hoof, 22; member of herd, 243; position of eyes, 178; prey of wolf, 226; shape of body, 124; skeleton of limbs, 21; smell of body, 165; sweating, 111; swiftness, 24, 195; tiptoes, 23
Horse-chestnut, buds, 119
House, of ants, 234; of caddis-worm, 75–76; of snail, 54
House-fly, 134. *See* Fly
Human being (Man), disguised, 206; language, 146, 151; meddling in animal and plant world, 266; smell of body, 165; teeth, 125; travelling, 37, 201; way of running, 23, of swimming, 35, of walking, 20, 23; where different from other animals, 195
Hunger, 2–3
Hunter, 165, 208
Hyacinth, 101, 119
Hydrogen, 59, 78, 80, 92–93

Insect, activity, 72; brain and nervous system, 183, 199; breathing, 72; childhood, 228; compared with bird, 37, 72, 233; concealment, 209; eggs, 218; extra senses, 169; flight, 36; food, 258; language, 150; legs, 15, 229; pollination, 260, 266; prey of birds, 82, 120, 224; sensitiveness to cold, 120; sense of hearing, 154, of sight, 183, of smell, 166–169, 258, of touch, 144; size, 37; skeleton, 14, 50, 72; wings, 42
Instinct, 202, 251
Intelligence, 202
Intestine, of bird, 128; of cat, 124; of earthworm, 133; of frog, 10; of human being, 86, 88, 106; of rabbit, 86, 124; of tadpole, 236; muscles, 17, 236
Invertebrate, 19, 50, 70, 72, 107, 130, 139, 150, 199, 208
Iodine, 94, 99, 102
Iris, 171, 176. *See* Eye
Iron, rusting, 57; in food, 78, 81, 95

Jam, as food, 84–85, 88, 246
Jaw, 125, 181, 229, 236, 258
Jelly-fish, 13, 153, 162
Joints, 15–16, 140, 142

Kangaroo, 20, 27
Keel, of bird's breast-bone, 45–46; of yacht, 31
Kidney, organ of excretion, 10–11, 62, 82, 89
Kitten, 146–147, 225–227, 239
Knee, of bird, 47, 49; of dog, 20; of horse, 21; of man, 61

Lamb, behaviour, 226–227
Language, of birds, 147–148, 160; of furry animals, 146–147; of human beings, 146, 151; of insects, 150–152; of smell, 151, 166; of touch, 151, 166
Lark (Skylark), 200, 220
Larva, of insects, 76, 218, 229; tadpole as, 219, 236
Larynx, 145. *See also* Voice-box
Leaf, arrangement on branch, 94; breathing-holes in, 92, 114; food of caterpillar, 228, of earthworm, 131–132; growth of new, 98, 103–104, 117; imitated by insect, 209; making sugar and starch, 93; shedding, 98, 116–118; storage in, 94, 100; wilting, 114–116
Leaf-insect, 208–210

Leg, of bee, 261; of bird, 27, 47; of cat, 9, 140; of frog, 27, 35, 67, 236; of fly, 259; of human being, 18, 20; of insect, 15; of kangaroo, 27; of snake, 55
Lens, of eye, 171–174, 182, 187
Leopard, 237, 243
Life, attempt to define, 1
Life-spot, of egg, 213, 217
Light, 3, 6, 171, 175, 176, 183, 186, 189
Limbs, fore- and hind- (*see also* Arm and Leg), control of, 191; crawling without, 50; necessity for joints, 15; of domestic animals, 20; of fish, 30 (*see* Fins); of human being, 15, 20; of insect, 50; of newt, 24; of turtle, 32; of whale, 32; position of, 24
Lime, in ear, 154, 158, 162; in shell of egg, 215; in skeleton, 14; in teeth, 215
Lion, 82, 96, 165, 176, 178, 180, 195, 205, 226, 237
Lips, 142, 145, 147, 191
Liver, as filter, 89; cat's food, 2, 84, 124; food-store, 77, 89, 124; of frog, 10; juice from, 88–89; oil content, 80; position, 86; vitamin content, 81
Livingness, tests for, 1–12
Living stuff, 12. *See* Protoplasm
Lizard, 55, 107, 122, 160–162
Lobster, 14; ears, 154
Lung, of bird, 38, 63, 149, 215; of frog, 10, 63, 67, 180, 235; of man 59; of land vertebrates, 63; of snail, 71; of turtle, 33; of whale, 32, 63; position in body, 19, 59

Mammal, behaviour of young, 226; brain, 197; breathing, 64; colour, 208; colour-blindness, 182; family life, 240; feeding young, 80; recognition by smell, 166; sense of hearing, 158; warm-blooded, 107, 120; winter sleep, 120
Man, 20. *See* Human being
Manure, 133–135
Marrow, 37
Mayfly, 76
Meat (*see also* Flesh); definition, 15; eaten by earthworm, 132; by maggots, 219; by kittens, 243; by tadpoles, 235; food-value, 124; protein content, 80
Medulla, 193, 197
Merry-thought, 46
Microbes, 135
Migration, of birds, 120
Milk, bee's, 247, 250; food of mammals, 80, 124, 200, 225–227, 243–244; pigeon's, 224
Milling, by hen's gizzard, 127; by earthworm's gizzard, 133
Mineral, ejected by earthworm, 133; in bone, 14; in diet, 81, 123; of shell, 215
Mole, 140
Monkey, 27, 178, 180, 182, 198, 203–204
Moth, antennæ, 167, 231; ears, 154; eggs, 212, 219, 228, 232; eyes, 168, 231; feeding, 135–136; pollinating flowers, 264; sense of smell, 167–169, 264; tongue, 136, 264
Moulting, by caterpillar, 230; by dragonfly larva, 232; by lobster, 154
Mouse, eye, 178, 187; feeding, 91–92, 123; young, 226
Mouth, 86, 92, 111, 125, 131, 169, 189, 199, 223, 230, 236
Movement, characteristic of animal, 6, 20; conscious, 16, 192; muscular, 200; plant, 5, 6, 114, 116; unconscious, 17, 191
Mud, 66, 122, 200
Mulberry, leaves, as food of silkworm, 219, 228
Muscles, control by brain, 189, 200; involuntary, 17; messages to and from, 140, 142; nature and work of, 15; need of energy, 59, 64, 77, 81; of arm, 16, 189; of bird, 44; of chest and diaphragm, 60, 193; of ear, 160; of earthworm, 52; of fish, 162; of gizzard, 127; of gullet, 53, 88; of heart, 17; of insect, 72; of larynx, 145; of snail's foot, 54; of stomach and intestines, 17, 87; voluntary, 16
Music, effect on animals, 159

Nectar, collected by bee, 72, 136, 246, 253, 260, 262–264; food of butterfly and moth, 136, 264, of fly, 258
Nectary, 253, 258, 260
Nerves, of eye, 172, 187; of frog, 10; relation to sense organs, 140, 190, to muscles, 191; to and from skin, 141, 192
Nervous system, of vertebrate, 190; of invertebrate, 199
Nests, making of, 200, 207, 220–222, 224, 240
Nestling, 222–224
Newt, 24–26, 107, 160
Nitrates, plant's source of nitrogen, 95, 116, 133
Nitrogen, 57–58, 78, 80, 92, 95
Nose, of bird, 64; of dog, 163, 182; of elephant, 136; of frog, 66, 180; of human being, 163, 169; of tadpole, 67; of whale, 32
Nostrils, of bird, 64; of crocodile, 180; of frog, 180, 235; of human being, 60, 163
Nursery, of bee, 247, 250; of ant, 234; of bird, 220, 224, 239
Nuts, as food, 80, 84, 121

Oar, duck's foot as, 34; frog's foot as, 35; man using, 30, 34; turtle's hand as, 34; wing as, 36
Oil, 80, 123, 166
Onion, 100–101, 169
Organs, defined, 9; of balance, 162; of digestion, 10; of excretion, 10; of frog, 10; of respiration, 10; of sense, 6; of snail, 54, 71; sweat, 109
Ostrich, 37
Ovary, 253–254, 257–260
Owl, carnivore, 96, 160, 178, 180
Oxygen, essential to life, 2, 11, 58, 60-66, 68–74, 76–78, 80–81, 92–93, 102–103, 114, 118, 120, 172, 215, 218, 265

Pain, 3, 140–141, 189
Pancreas, 86, 88
Parrot, foot, 27, 148–149, 202
Partridge, 148, 207, 220, 222
Paws, of dog, 204; of rabbit, 23
Perch, 48–49
Petal, 252–254, 258–260
Pig, hoof, 22; 28
Pigeon, air-sacs, 65; feeding young, 224; position of eyes, 178; speed, 37; tail, 41; town-dwelling, 225
Pine-needles, 132
Plant, breathing, 63, 92; distinguished from animal, 6; food-making and feeding, 92, 116, 265; growth, 7, 91; helping animal, 256, 265; movements, 5, 114, 116; need of food, 6, 91; power of having young, 4, 7; protein, 80; repair of parts, 6, 91; sensitiveness, 6; water-supply, 102, 114; winter sleep, 116
Plant-eater, 78–80, 123
Pollen, 247, 253, 258, 264
Poppy, 118, 186
Pores, of skin, 82, 109, 116
Potato, 78, 98–100, 118
Proboscis, 136
Protein, body-building value, 81, 214, 224, 247; composition, 80; digestion, 85, 88; food of animals, 123; manufacture by plants, 95; storage, in bean, 102, 104, 214, in egg, 80, 214, in hive, 247, in potato, 99
Protoplasm, life-spot, 213; living stuff, 12–14; need of food, 80, of warmth, 58, 105–106, 108, 117; protein content, 80; water content, 82

Pulley, 47, 49
Punt, 29, 55
Pupa, of ant, 235; of bee, 247; of butterfly, 232; of silkworm moth, 231
Pupil, 171, 176
Purring, 146, 226

Queen bee, 122, 248; wasp, 122

Rabbit, colour, 206; ears, 160; eyes, 178, 180; food, 123; intestine, 85, 124; position of feet, 23, 26; prey of dog, 164, 205; sense-organs, 137; teeth, 124–126
Rain, 134, 162
Rainbow, 175, 186
Rectum, 85, 88
Reptile, 181, 197
Response, to stimulus, 3, 138, 161, 189–190
Retina, 171–172, 182, 187
Ribs, 19, 55, 60, 65, 71, 77
River, 12, 62
Robin, 111, 121, 222
Rook, 240
Roots, 95, 100, 116, 121, 133
Rowing, by bird in air, 36; by turtle under water, 32
Running, by dog, 26; by horse, 26; by human being, 23

Saliva, a digestive juice, 86, 127
Salmon, 28–29
Salts, in food of animals, 78, 85, 123; in food of plants, 95, 104
Sand, 133, 154, 206
Sap, 93–95, 119
Savages, hunting and fighting, 237, 243
Scales, of fish, 31, 235; of hyacinth bulb, 101; of leaf-bud, 119; of snake, 55
Scent (Scents), 164, 168, 222, 264
Sculling, 30
Sea-birds, 240
Seagull (Gull), 41, 111, 240
Seed, carried to ground, 254, 256; compared to egg, 4, 8, 102, 212; food of animals, 121, 222; setting, 260, 263
Seed-coat, 102–103, 214
Seed-leaves, 102–104
Seedling, 103
Senses, 137, 169
Sense-organ, antennæ as, 169; bath-sponge without, 7; ear as, 10, 153, 158, 189; eye as, 10, 170, 181, 189; nose as, 137, 189; position of, 138; of insects, 139; of muscles and joints, 142; of taste in man, 137, 141, 189; skin as, 137, 141, 189; tongue as, 137, 142; what they are for, 6, 195; whiskers as, 10, 144
Sensitiveness, of animal, to light, 3, to pain, 3, to smell and taste, 6, to touch, 3, 141–144; of plant, to light and moisture, 6, to touch, 5
Shark, 166, 182
Sheep, care of young, 244; chews the cud, 128; dependence on grass, 265; distributor of seeds, 256; flock, 243; foot, 22; hoof, 22; prey of wolf, 96, 226
Shell, of egg, 212–217, 220, 222, 228; of snail, 54, 71–72
Shoot, of bean-seedling, 102–103; underground, 99–100
Shoulder-blade, 18, 45, 47
Side-line, of fish, 139
Sight, 170. *See* Eye
Silk, 230–232
Silkworm, 219, 228
Sinew, 16. *See* Tendon
Skeleton, of bird's arm, 39; of bird's breast, 45; of dog, 20; of human being, 17; of insect, 14, 50, 72; uses and ways of wearing, 14
Skin, blood-vessels, 109, 141; of caterpillar, 208, 229; of dragon-fly larva, 232; of earthworm, 52, 70, 144, 184; of frog, 66, 68, 122; of leaf, 92; of lizard, 66; of potato, 99; of snail, 70; of snake, 55; organ of touch, 141, 156; pores, 82, 109, 116; sensitive to pain, 141, to temperature-change, 141, 192
Skull, 18, 157, 162, 194
Sleep, of animals, 114, 120; of plants, 114, 116
Sleeping place, of starlings, 240
Slow-worm, 161–162
Slug, food of slow-worm, 162; limb-less, 50; softness, 14; touch-organs, 144
Smell, organ of, in man, 163, 182; stimulus, 3; under water, 166
Smell-track, 165
Snail, breathing, 70; cold-blooded, 107; crawling, 54; eyes, 183; garden-, 71; pond-, 72; sensitiveness to touch, 144; shell, 54, 71; skin, 70
Snake, cold-blooded, 107, 122; crawling, 54; scales, 55; shape, 54, 56; skeleton, 55; skin, 55
Snipe, 222
Snowdrop, 101
Soil, earthworms and, 51, 130, 133; source of water for plants, 93, 103, 116, of nitrates for plants, 95, 116, 133
Sole, of man's foot, 18, 23; of snail's foot, 54
Song, of birds, 148
Sounds, 140, 144, 150, 153, 156, 161, 166, 189
Sparrow, 121, 222, 225–226
Spawn, 217. *See* Egg, of frog
Speech, 146, 194
Spider, feigning death, 206; food, 78, 96; sensitiveness to vibrations, 156; prey of birds, 206
Spinal cord, 12, 18, 190, 192, 193, 197
Spinning, by silkworm, 230–231
Spittle, 87. *See* Saliva
Spring, breeding season of frog, 66, 216, of bird, 200, 221; effect on plants, 98, 117–118
Squabs, 224
Squirrel, food, 84, 121; gliding, 36; winter sleep, 77, 120–121
Stag, 165–166
Stamens, 253, 258–259, 261
Starch, carbohydrate food-stuff, 78, 81; digestion of, 85, 87, 89; storage, in bean-seed, 102, 104, 214, in leaf, 94–95, in potato, 99, in turnip, 100; testing for, 94, 99, 102
Starch-print, how to make, 94
Starling, nesting, 220, 240; 225
Starvation, of plant, 93; of animal in winter, 119; what it means, 77
Steering, by bird, 41; by oars, 34; by turtle, 34
Stereoscope, 174
Stick-insect, 210–211
Stigma, 254, 259–260, 263
Sting, 248
Stimulus, definition, 3; of light, 6, 189; of moisture, 6; of sound-waves, 153, 189; pain as, 189
Stomach, blood-supply, 89; gateway from, 86, 88; making gastric juice, 88; movements, 88, 192; of bird, 127, 223; of camel, 82; of cow and sheep, 128; of fish, 68; of frog, 10–11; of fly, 134; of human being, 86, 88, 106, 140, 191; of young mammal, 227; position, 19, 53; rested by sleep, 114
Stomach-ache, 140
Storage, of fat in body, 77, 120, 122, 231; of food in bulb, 100–101, in egg, 214, 218, in leaves, 98, in potato, 99–100, 119, in roots, 100, in seed, 102–104, 214, in stem and branches, 98, 118; of fuel, 77; of honey, 246, 248, 262; of nuts, 120; underground, 98
Strawberry, 252, 256
Stream-lining, 28, 31, 37, 45, 110
Sucker, 209
Suction-pump, 60
Suet, 10, 80

Suffocation, 69–70, 73
Sugar, absorption, 87, 89; burning, 59, 62, 80; carbohydrate food-stuff, 78, 81; composition, 59; digestion, 85, 89, 128; food of bee, 166, 186, 247, of fly, 134; in carrot, 100; in leaf-bases of hyacinth, 101; manufacture by green plant, 92–94; solubility, 93, 95
Sulphur, in food, 78; ingredient of protein, 81, of protoplasm, 12
Sunlight, 93–94, 117, 218
Swallow, 120, 200–201, 220, 222
Swallowing, 66, 68, 87, 92, 127, 133
Sweat, 109–111, 116, 170
Sweet-bread, 86. *See* Pancreas
Swimming, by fish, 28; by frog, 35; by man, 34, 225; by land-animals, 28; by tadpole, 34, 218; by turtle, 33; by whale, 32

Tadpole, breathing, 66–68, 218, 235; compared with fish, 235; development, 218, 235–236; eyes, 236; feeding, 236; intestine, 236; swimming, 34, 235; tail, 34, 218, 236
Tail, of bird, 40; of earthworm, 51, 131; of fish, 30; of tadpole, 34, 218, 236; of whale, 32
Taste, as stimulus, 3; of bread, 87; of frog's spawn, 218; sense of, 137, 169
Taste-buds, 169
Teeth, of dog, 125; of cat, 126; of frog, 236; of man, 87, 125, 128, 145; of rabbit, 124; made of lime, 215; used as weapons, 196, 205
Telephone, 155, 190, 195
Temperature, changeable, 107, 121; constant or even, 108, 112, 121, 217, 222; effect on plant, 98; in bee-hive, 250; normal, 108, 110; of air, 105; of animals' bodies, 106, 120; of plants, 117; of room, 107; of stones, 106; of water, 105; of young bird, 112; sensitiveness to changes in, 141
Tendon, nature and use of, 16, 45; of bird's breast-muscles, 46–47; of bird's toes, 48–49
Thermometer, 107–108
Thinking, 193, 197, 204
Thirst, 82
Throat, 65, 146, 149, 157
Thrush, 200, 220, 222, 224–225
Thumb, of bird, 39; of dog, 26; of human being, 18, 22, 24
Tiger, carnivore, 28, 82, 165, 195, 243
Tit, 220–221, 224
Tobacco-plant, 264
Toes (Toe), of bird, 34, 47; of frog, 35; of human being, 18, 23, 60; of turtle, 33; of land mammals, 20, 33
Tongue, of bee, butterfly and moth, 136, 264; of cat, 126, 225; of dog, 112, 126; of fly, 134, 259; of silkworm, 230; use in feeding, by human being, 87, as sense-organ, by man, 137, 142, 169, in word-making, by man, 145, by parrot, 148
Torpor, 121. *See* Winter-sleep
Tortoise, 14, 33, 196
Touch, in earthworm, 131; in furry animals, 143; in man, 137, 141; in insects, 144; language, 150
Touch-corpuscles, 141, 144, 156
Touch-spot, 141
Trachea, 59. *See* Windpipe
Tree, arrangement of leaves, 94; buds, 119; food-store in, 118; home of birds, 220, 240; immobility, 5; shedding leaves, 98, 116–118; shelter of animals, 205, 265; water-supply, 117
Trumpet-snail, 72
Trunk, the body, 189; of elephant, 92, 136
Tuning-fork, 156
Turnip, 100, 102
Turtle, swimming, 32–34

Ultraviolet, 171, 175, 186
Urine, 11, 89, 95

Vane, of feathers, 40
Vegetarian, 78, 80, 96, 119, 132, 236
Veins, 10, 62
Ventilation, of bee's hive, 250–251; of caddis's house, 76
Vertebræ, 17
Vertebrate, 19, 63, 130, 149, 157, 160, 176, 183, 187, 198, 208
Vibrations, 144–145, 153, 158
Vitamins, 81–82, 123, 214
Vocabulary, 146
Vocal cords, 145, 149, 160
Voice, 145, 149–151, 159
Voice-box, 145–146, 149

Wading, 28
Walking, all-fours, 20, 24; by newt and crocodile, 24; by four-legged mammals, 26; two-legged, 20, 27, 47
Warm-blooded, 107, 121, 239
Warmth, importance for life and growth, 103, 105, 213, 215, 218, 225, 229, 250
Wasp, antennæ, 167; breathing, 73–74; hibernating, 122; sight, 185; social life, 251
Waste, from the body's working, 10, 59, 62, 65, 74, 76, 92; made use of by plant, 95, 265
Water, absorption by intestine, 70; breathing under, 66, 72, 74; buoyancy of, 13, 29, 32, 36; composition, 93; evaporation, 106, 109, 111, 116; in diet of animals, 82, 85, 213, 214, 218, 247; necessary for plant life, 93, 95, 102, 114; seeing under, 182; smelling under, 166; swimming under, 28; temperature, 105; turning to steam, 2; waste from body, 59, 62, 82, 89, 92
Water animals, 28–30, 180–182
Watering, of mouth, 87, 189
Water insects, 74–76, 232–233
Wax, of bee's comb, 246, 250
Web, of bat's wing, 42; of duck's foot, 34; of feather, 40; of frog's foot, 35; of spider, 156, 221
Whale, 32, 63–64
Whiskers, of cat, 1–2, 10, 143
Whistle, 148, 156, 158
White, of egg, 80, 213, 214, 217–218; of eye, 176
Wild cat, 143, 239, 243
Windpipe, of bird, 64, 149; of human being, 59–60, 87, 145; of mammals, 64
Wing, of bat, 42; of bird, an arm, 38, how folded, 39, how moved in flight, 40–41, 46–47; of dragon, 42; of insect, 42, 209; of water-beetle, 74
Winter, effect of, on animals, 119, 122; effect on plants, 98, 116
Winter sleep, of animals, 66, 77, 120, 122; of plants, 116–119
Wireless, 169, 175
Wish-bone, 46
Wolves, 129, 226, 243
Woodpecker, 220
Words (Word-making), 145–146
Worker, bee, 248–251
World, news of the, 137–140; seen by animals, 176–188; smell-and-touch, 140; underground, 140; under-water, 139; view of the, 174
Worm, 51. *See* Earthworm
Worm castings, 133
Wrist, of dog, 20, 23; of horse, 21, 24; of human being, 18, 39; of rabbit, 23
Writing, 196

X-rays, 171, 175

Zebra, 20, 82, 96, 243, 265

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